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PART I

REVIEW OF STATE MANUFACTURE

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CHAPTER I.

THE ROYAL ORDNANCE FACTORIES.[1]

At the outbreak of war, State manufacture of munitions was already a long established fact. In August, 1914, it was being carried out at the Royal Ordnance Factories and at the Royal Aircraft Factory, Farnborough. The Royal Ordnance Factories consisted of (1) a Small Arms Factory at Enfield where rifles, bayonets, swords and similar articles were being produced and machine guns repaired, (2) the Gunpowder Factory at Waltham Abbey, which was making cordite, tetryl and small quantities of fuse compositions, and (3) a group of factories at Woolwich, which produced guns, shells and practically every other class of munition and, together with other establishments concerned with inspection, stores, research and instruction, formed the Woolwich Arsenal.

I. Functions of an Ordnance Factory.

Before proceeding to give some account of the development of the Ordnance Factories and to show with what measure of success they fulfilled during the war the functions for which they were designed, it will be well to summarise briefly what those functions were.

Various considerations may be urged in favour of the State manufacture of munitions. The ordinary laws of supply and demand do not apply in the case of the most costly and important munitions of war, the sources of supply being strictly limited, and effective competition non-existent. The ability of the State to manufacture for itself may be in such cases very important in arriving at fair prices, while for stores, in the manufacture of which more normal conditions obtain, the cost of production in a State factory may form a valuable check on trade prices. Some such establishment seems essential, as a source of the specialised knowledge of manufacture required for government inspection and control, and as a headquarters for the improvement of design, as well as for the establishment of a standard of excellence in workmanship. From the point of view of economy the execution of repairs by a State factory has many advantages, since it is very difficult to gauge beforehand the amount of repairs required, or to check the cost of repairs done under contract, while it is of value that repair work should be undertaken in the factory which is most closely in touch with design, in order that failures and weak construction should be brought to the immediate notice of designers. Secrecy, which is often essential in armament development, is more easily attained in a government factory.

Collation of designs from all sources was regarded in 1917 as a special function of an Ordnance Factory, but experience at Farnborough showed that this might lead to jealousy on the part

[1] For a detailed account of the development and work of each of these factories during the war, see Vol. VIII, Part II, Chap. I.

of contractors and that collation of design was more properly the function of a special staff independent of manufacture. The special machinery and highly skilled personnel of a government factory are, however, invaluable for experimental work and the production of experimental stores, and all kinds of special stores which are required only in small quantities, while the same attributes are of value in enabling it to act as a balancing capacity for the production of urgent stores or making good the failures of other producers.

The aspect of a State Ordnance Factory which attracted most attention before the war was its power of providing a reserve of productive power in times of emergency. The experience of the war has, however, proved that no national arsenal is capable of dealing with the output needed for a European war. The magnitude of present-day warlike operations has shown that the real reserve for war is the whole of the manufacturing power of the country. Opinion as to the principal duty of an Ordnance Factory has accordingly changed, and though a State factory still requires a moderate expansive power to meet small wars on the frontiers of the Empire, its function as a centre of experience and knowledge from which instruction may be quickly propagated throughout the country has now assumed far greater importance. To fulfil this rôle the Arsenal should be experienced in the manufacture of every kind of warlike store, and have plant for their production, so that it may be in all cases relied upon for exact knowledge and experience in manufacture. Provision must be made for the training of personnel of new factories when expansion is suddenly required. The Arsenal should include equipment on a large scale for making gauges for issue to firms when emergency arises. It should also be in possession of complete knowledge of the manufacturing capacity of the country as a whole and should be given every opportunity of keeping that knowledge up to date.

II. Early Development of the Royal Ordnance Factories.

In order to form any adequate idea of the conditions existing at the Ordnance Factories on the outbreak of war, and to appreciate the effect of these conditions upon the development of the factories during the war, it is necessary to consider at some length their previous history. Both Woolwich Arsenal and the Royal Gunpowder Factory date from Tudor times, though the latter was not purchased by the State until 1787. The Royal Laboratory was moved in 1695 from Greenwich to Woolwich, where there were also in 1717 a foundry for brass ordnance, yards for building gun carriages, a shot house and powder house, a proof yard, carcase barn and firework house. Woolwich became the headquarters of the Royal Artillery about 1719, and in 1741 a school of instruction for gunners—the Royal Military Academy—was established there. The ordnance stores were transferred from the Tower of London to Woolwich about 1800, but it was not until 1805 that the whole collection of these establishments received the name of the Royal Arsenal. At the same time (1804) the nucleus of the Royal Small Arms Factory was established at

Enfield. In the years that followed the close of the Napoleonic wars, the State establishments for making munitions were neglected. Shortly before the outbreak of the Crimean War a plan was set on foot for making small arms by machinery in a single State factory of unprecedented size; but the project was reduced, mainly by reason of its cost, to an extension of the Enfield factory, while the Crimean war itself proved that the Woolwich factories were inadequate for their purpose. As a result they were reorganised and modernised. A shell factory was built in 1855 and a gun factory for the manufacture of the Armstrong rifled gun in 1856–8. Several hundreds of women were employed in making cartridges until 1872 when, for reasons of social and economic well-being, they were all dismissed. In the same year the Arsenal was enlarged by the inclusion of the former naval dockyard, which had been closed since 1869.

(*a*) PRE-WAR ADMINISTRATION.

The Royal Ordnance Factories consisted in 1886 of five manufacturing departments, the Gun Factory, the Carriage Factory and the Royal Laboratory at Woolwich, where guns, carriages and ammunition of all kinds were made, Enfield and Birmingham Small Arms Factories, and Waltham Abbey, where gunpowder of all kinds was then manufactured. Each of these five departments was under a military superintendent with a civilian manager acting under him. Each department was entirely independent of the rest, and the military superintendents had supreme control of the factory under them, and a free hand in its administration provided they did not spend more money than the amount allotted to them. The superintendents, who were appointed for five years only, were responsible through the Director of Artillery and Stores to the Surveyor-General of Ordnance. Each factory designed the articles which it manufactured in drawing offices under the control of the managers. The departments also tested and passed their own manufactures as well as the articles manufactured by the trade, with the exception of gunpowder, that for ordnance being proved at the Gun Factory and that for small arms ammunition at the Royal Laboratory. The superintendents and managers decided what tests should be applied to all the articles they manufactured with the exception of steel forgings, the tests for which were framed on the recommendation of the Ordnance Committee.

Stores for all the manufacturing departments were bought by the Director of Contracts, usually by a system of limited tender, a few firms only being asked to tender for the articles required. The reason for this limitation was that the superintendents of the factories, when they sent their requisitions to the Director of Contracts, usually recommended the firms that should be invited to tender, and though the Director of Contracts had power to add to the number of firms recommended, he did not usually exercise that power against the judgment of the manufacturer who had technical knowledge. The superintendents had a limited power of purchasing small articles without reference to the War Office.

All orders were given to the departments through the Commissary General of Ordnance in the form of what were technically termed "extracts," viz., extracts from letters addressed to the Commissary General by the Director of Artillery and Stores. Small arms alone were excluded from his action, orders going to Enfield through the Ordnance Store Officer at Weedon. In addition to the consolidated demands for the whole year, there was an enormous number of supplementary demands, no less than 4,000 extracts being issued to the manufacturing departments during 1886.

It was clear that in 1886 the administration of the Ordnance Factories was not sufficiently centralised. The Director of Artillery and Stores, the nominal head of all the factories, was too much occupied with other duties to exercise effective supervision or to harmonise the work of the various factories. Grave practical difficulties were the result. For instance, changes in the design of guns which affected the gun carriages were made by the Gun Factory without informing the Carriage Factory, which continued to manufacture to the old design until practical experience disclosed the error.

The necessity that the officials in charge of the manufacture of warlike stores should have practical knowledge of their use was recognised throughout the history of Woolwich. The military staff was selected almost entirely from the Royal Artillery, and to qualify for appointments to the manufacturing departments, candidates had to pass through the senior class of the Artillery College, and before taking this course, six years' military service was necessary. Under the superintendents of factories there were assistant superintendents, captain inspectors, and captain instructors, the latter being in charge of the numerous officers and non-commissioned officers who received instruction in the Arsenal. The superintendents were usually appointed from the ranks of the assistants. The managers were invariably civilians, and had the direction of manufacturing operations.

A committee appointed in 1886, under the chairmanship of Lord Morley, to consider the administration of the Ordnance Factories, reported that the constant breaks in continuity of management due to the quinquennial changes of superintendent were a drawback and that those directly responsible for administration should hold office at the pleasure of the Secretary of State. They also raised the question of the advisability of having military men in charge of the administration of the factories, since it did not appear that a military career gave opportunities for acquiring a knowledge of factory organisation and manufacturing processes. It seemed to the committee that this, combined with the quinquennial changes, placed the superintendents too much in the hands of their civilian managers. The chief argument in favour of the limitation of these posts to military officers was that military experience was of the greatest value in designing and inspecting munitions; but it was pointed out that such experience was not required in manufacturing articles to conform to a given pattern and to stand defined tests. In these operations other qualities, such as capacity for organisation and knowledge of manufacturing processes and materials, were more important, and were more generally

acquired in civilian than in military life. Provided, therefore, that the military element was always present in the designing and inspecting branches, the committee recommended that for the superintending of actual manufacture the best available men should be selected, and they held that under the existing conditions the field of selection was restricted within dangerously narrow limits.

In order to secure co-operation between the different factories, the committee proposed to place them all under one Superintendent of Ordnance Factories who should be of military rank. The main object of the committee was to separate design and instruction—the military side, from manufacture—the civilian side, and with this object in view they advised that the Superintendent, for the performance of his duties connected with general superintendence, design and experiment, should be assisted by officers, who together with the instructors, should form his permanent staff, while directly responsible to him for manufacturing arrangements there should be a Chief Mechanical Engineer, a civilian, whose assistants—also civilians—would be managers of the various factories. Since in accordance with War Office procedure the Superintendent could be appointed only for five years, they recommended that he should be reappointed at the discretion of the Secretary of State. In view of the distance of Waltham and Enfield from Woolwich it seemed advisable to have superintendents for each of these factories who should report to the Chief Superintendent. This arrangement seemed to lose sight of the fact that the reserve from which to draw the Chief Superintendent and inspecting staff would soon disappear owing to the complete failure to provide a supply of military officers with previous training in actual manufacture.

These recommendations were carried out to a limited extent only. The administration of the Ordnance Factories was centralised under a Director-General, not necessarily a military officer, reporting to the Financial Secretary, and a separate Department of Inspection was created at the Arsenal and placed under the Director of Artillery, who reported to the Commander-in-Chief, the office of Surveyor-General of Ordnance having been abolished. The factories thus lost the duty of inspecting trade products, but they retained certain inspection duties in respect to their own. The recommendations with regard to the appointment of a Chief Mechanical Engineer were not carried out, and military officers remained as superintendents of the various factories, the five year limit of their appointments being abolished soon after. The reasons given for the elimination of the military element did not seem to be justified, as the organisation of labour was good, and the cost of production was low.

Subsequent changes in the administrative control of the factories by the War Office had little effect on their immediate administration, which remained under a single Chief, whose title was altered in 1899 to Chief Superintendent of Ordnance Factories. In August, 1914, section A4 in the department of the Director of Artillery, was responsible for the personnel of the Ordnance Factories as well as for the Inspection Department.

The reorganisation of the Ordnance Factories was decided on in 1887 and was mainly carried out by Sir William Anderson, who held the post of Director-General of Ordnance Factories from 1889. A central office was established, through which all communications between the factories, the War Office and the Admiralty were to pass, and the work of the stores, cashiers and works accounts branches was transferred thither. The Chief Superintendent was assisted at the central office by a secretary who dealt with all technical questions, and a civil assistant responsible for the stores, finance, works accounts and pay branches; but each superintendent still retained his own office with its own system of registration, its own copies of all correspondence, and its own drawing and designing offices. This extremely limited centralisation was partly due to the decision to retain the factory superintendents, who naturally wished to maintain their independence as far as possible, and partly to the impossibility, owing to the lay-out of the Arsenal, of providing sufficient accommodation in the central offices. Rooms had been provided there for the superintendents, but not for their staffs, with the result that a superintendent, when in touch with the Chief Superintendent and the central registry, was out of touch with his own staff, with which the greater part of his work was carried out, and the superintendents soon ceased to use the accommodation provided for them in the central offices. The central registry was insufficiently accessible for any separate factory to rely on it for reference, consequently each factory maintained its own registry, though the only strictly clerical duty remaining in the province of the factory superintendents was the preparation of the wages accounts. This state of things was altered after 1902 by the provision of offices for the Chief Superintendent and the factory superintendents in a new building, centrally placed, and a set of records was established there for general use.

A certain amount of concentration was effected by readjustment of work between the factories. Each was in 1887 completely equipped for the production of those classes of stores with which it dealt. Each had its own foundries, forges, railway engines and rolling stock, but during the next ten years nearly all wood-work was concentrated in the Carriage Department and a boiler repairing shop for all the factories was opened in the Gun Factory. At the same time the departments were encouraged to make the freest possible use of each others' workshop resources.

Up to 1888 an officer of the Royal Engineer Department, stationed at Woolwich Arsenal and known as the Inspector of Works, was in charge of building and various engineer services for the Ordnance Factories and other departments of the Arsenal. In 1888 his title was changed to Superintendent of Building Works, and he became the subordinate of the newly appointed Director-General of Ordnance Factories, holding his appointment at the pleasure of the Secretary of State. To him were transferred the general Arsenal services, such as the gas factory, the railways, hydraulic establishments, telegraph, telephone and coaling arrangements and a central electric station, which replaced the electric lighting plants which were beginning to

grow up independently in the several factories. The separate store branches of the factories were centralised, the store branch of the central office holding and issuing materials for all Arsenal factories and the Building Works Department. At Woolwich many stores were delivered direct to the factories, only passing through store on paper; those which actually passed into the custody of the Central Stores Department were kept in buildings which were formerly the storehouses of the several factories, the centralisation being in the main administrative. No site was available for a central store, even had such been desirable from the point of view of convenience in distribution. The introduction in 1888 of a separate vote for the Ordnance Factories as a whole made it necessary to go a step further and to centralise at Woolwich the general administration of the outlying factories, though stores were delivered direct to those factories and held and issued by their superintendents.

It was Sir William Anderson's wish to carry centralisation very much further and to amalgamate all the factories as proposed by Lord Morley's committee. He also planned a revision of the lay-out of the Arsenal, but this did not materialise in his lifetime, and by 1901, the policy of retaining the services of superintendents in charge of the manufacturing departments became quite clearly defined. His successor, Sir Frederick Donaldson, revived the question of the unsuitability of the lay-out and equipment of the Arsenal, but the difficulties of reorganisation were enormous, and the only result was a grant of £175,000 for machinery spread over three years under conditions which went a long way towards defeating the object in view.

In the early part of 1909 the Royal Gunpowder Factory at Waltham and the Royal Small Arms Factory at Enfield were removed from the control of the Chief Superintendent of Ordnance Factories and placed under the charge of a single head known as Superintendent of Waltham and Enfield. Accounts for Waltham and Enfield were still kept at Woolwich, but there were three separate offices at Waltham and Enfield, one for each factory, and one for the Building Works Department. These offices were centralised when the superintendence of the two factories was united. In October, 1917, the factories were once more separated and placed under separate superintendents, as conditions were so different in the two factories, the work in one being of a highly skilled mechanical nature and the other entailing special knowledge of explosives, but no very special skill among the employees.

The policy whereby the Arsenal was the centre both of manufacture, inspection and storage, to a great extent for both Services, led to great congestion at Woolwich after the outbreak of war. The fact that filling of nearly all ammunition was carried out at Woolwich during the first eighteen months of the war added to the confusion, components from contractors passing into the Ordnance Stores and being issued to the filling factories as required. A stream of stores and components poured into Woolwich from all parts of the country and from the United States and Canada. At first these included all army stores whatsoever, but the formation of subsidiary stores diverted

a certain amount. Throughout the war, however, large stores were held at Woolwich both by the Deputy Director of Ordnance Stores and the Superintendent of Ordnance Stores, and added greatly to the difficulties of production there, whilst the presence of such large stocks of explosives and filled ammunition at the Arsenal very greatly increased the danger risks.

The recommendation of Lord Morley's committee with regard to design aimed at the centralisation of design within the Arsenal and the strengthening of the control of the Ordnance Committee. They advised that the Superintendent of the Ordnance Factories should be responsible for the initiation and elaboration of design, having under him a department in which should be concentrated the several drawing offices then distributed between the various factories. He should be aided by advisers from his own staff, the chemist of the War Department, the Chief Mechanical Engineer and such naval and military officers as he should, after consultation with the Director of Artillery and Stores, call to his assistance. The functions of the Superintendent under this head should be limited to such designs as were prepared in the manufacturing departments and he should not be in any way concerned with inventions or designs of private persons. Such designs, as well as those prepared at the Arsenal should, at the discretion of the Director of Artillery, as was the existing rule, be submitted to the Ordnance Committee. These recommendations were not carried out. It was considered that the transfer of all drawing and designing to a central office would weaken the responsibility of the superintendents in the designs of their own productions.

(*b*) Growth and Lay-out.

The story of the development of the Ordnance Factories is bound up with the question of the general policy of the Government in obtaining munitions of war. Just before 1859 England had relied very largely upon supplies from the Government factories. The experience of the Crimean War led to a change of policy, and from 1859 the system was adopted of obtaining munitions partly from the trade and partly from factories under direct Government control. Lord Morley's committee in 1887 favoured a very considerable reliance on the trade.

> " Not only does it stimulate inventors and manufacturers to vie with one another in producing the best possible articles, but it tends also to widen the area of production, so that in time of pressure . . . the requirements of the service would be more readily supplied."

They deprecated the large discretion allowed to individual superintendents in the matter of extensions, and advised that any further expansions should be jealously watched and controlled by the War Office.

The South African war proved the Ordnance Factories to be capable of the expansion required for a war of that magnitude, but the pressure was at times very great, and since the factories were then

called upon to meet the demands of the land service only, it was recognised that a greater expansive power must be provided to meet the requirements of a war involving both land and naval forces. The war had also brought to light the fact that considerably more time was necessary than had been anticipated for the armament firms to reach their full capacity, and that they were liable to fail entirely in the production of certain essential components, as happened in the case of fuses. It appeared, therefore, that both trade and Government factories needed fostering and the principal difficulty was to determine a fair distribution of work in peace time between the Ordnance Factories and the armament firms in order to create a certain reserve capacity in both, without involving impossibly uneconomical production. Before the South African War the general arrangement was to allocate orders equally between the two sources of supply, though to a certain extent allocation depended on comparative prices. After that war the proportion was changed, roughly a third being assigned to Woolwich and two-thirds to the trade, this division applying more particularly to gun manufacture and being less definite in the case of other stores.

A scheme put forward in 1900, included proposals for increasing the productive power of the Ordnance Factories at a cost estimated to exceed £1,000,000. This programme was referred to a committee presided over by Sir F. Mowatt, for consideration as to how far the trade could be relied on for expansion required in time of war. The committee expressed the opinion that the factories should be so organised as to be able materially to increase their ordinary output in times of national emergency, or in the event of temporary failure of deliveries from the trade, but stated their conviction that this reserve power could only exist so long as the work assigned to the factories was well within the capacity of its normal staff working the ordinary number of hours per week. It was therefore essential either that the ordinary demands on the factories should be reduced or that large additions should be made to the buildings, plant and staff. The committee finally pronounced in favour of the former alternative, at the same time recommending certain additions to plant and buildings which, though less comprehensive than those proposed, were yet considerable. These recommendations were adopted and carried out by the Secretary of State with the result that in 1907 the equipment of the Arsenal was considerably more effective than it had been before the South African war. It became the policy of the War Office to provide a capacity for rapid expansion at Woolwich to tide over the first stages of a war before the firms were in a position to reinforce their efforts. During the same period the staff at the Arsenal had been systematically reduced, with the result that in 1905 a large proportion of the machinery was standing idle and the cost of production at the Ordnance Factories was becoming very large. Another committee, under the chairmanship of Sir G. H. Murray, was then appointed to consider among other things whether Government production could be advantageously replaced by private enterprise, and if so to what extent and on what terms. This committee reported in March, 1907. They assumed that the ideal

would be that the Arsenal should not be allowed to expand beyond the minimum point of economical production, consistent with the power of rapid expansion, but they found that the principle of economical production was incompatible with that of rapid expansion, and that the power to expand was more important than economy. They obtained from the superintendents of the various factories figures giving approximately the greatest number of workmen who could be efficiently employed on the existing plant and the smallest nucleus establishment from which this maximum number could be reached without unduly hampering production. They held that the proper establishment of the factories lay at this minimum, and that work should be allocated to the factories sufficient to keep this number fully employed, all surplus requirements being made up by recourse to trade sources. It had been found that the former system of allocation led to inconvenient fluctuations in the work at Woolwich, where no organisation existed, as in the trade, for transferring employees to other work when the demand for munitions was small. It was admitted that special enquiry might be necessary to decide the exact figures for the minimum nucleus, and those below were suggested.

	Maximum.	*Minimum.*
Royal Laboratory	13,000	3,500
Gun Factory	5,000	2,000
Carriage Factory	3,700	2,500
Royal Gunpowder Factory	1,500	600
Royal Small Arms Factory	3,500	2,000

The economic question of the effect upon the district of the discharges from Woolwich was becoming serious in 1907, and it became necessary to explore the possibilities of utilising the capacity at Woolwich for the production of stores other than munitions of war. Woolwich was equipped with machinery of a very varied and comprehensive nature, and it was suggested that other Government stores, such as barrack and hospital stores, camp equipment, accoutrements, harness and saddlery, should be manufactured there. It was, indeed, urged in some quarters that the Royal Arsenal should, in time of peace, be regarded as a great State manufacturing department, which should be utilised in meeting the requirements of all Government Departments, so far as its capacity allowed. Apart from the consideration that it was inadvisable that the Government should compete with trade, the contention of the Chief Superintendent that the *raison d'être* of the factories was that they should be prepared for sudden emergencies appeared to be unanswerable. The machinery of the Arsenal, though in itself applicable to general engineering, was arranged for a particular sequence of operations to produce a particular article, and if such machinery was diverted from its proper production, it might be impossible to retransfer it without loss of time, and serious danger to the country might ensue. Moreover, if work other than the manufacture of warlike stores was undertaken for other Departments it would have to be under the condition that immediately on the outbreak of war such work would have to be set aside, and this might be very inconvenient to the Departments concerned.

It seemed necessary to face the fact that to ensure the country against danger from sudden emergency, economy must take a second place, that in peace time a large proportion of the machinery of the Arsenal must stand idle waiting for the emergency to arise, and that a working staff must be retained adequate to control and instruct the additions to the army of workers which would be necessary to man the machines which, during peace time, were held in reserve. It was, however, suggested that the Navy might increase their orders upon the Arsenal for heavy gun mountings, but this idea was rejected by the Admiralty.

A committee appointed in 1909 to enquire into the organisation and resources of the factories advised that the conditions then obtaining were quite different from those of 1900, since the Army and Navy now had reserves of guns and stores sufficient to tide over the early stages of a war, while private factories had expanded to such an extent that each had a considerable reserve of plant to meet emergency orders. This seemed to justify a modification of the policy recommended in 1900. The committee's recommendations dealt chiefly with the reserves of machinery, the establishments having by that time been reduced to something nearly corresponding to the minimum. The expansion of the factories between 1897 and 1907 had been very great. The capital value of the buildings rose from £624,312 on 1 April, 1897, to £1,096,332 on 1 April, 1907, and this in spite of the fact that during the intervening ten years £405,426 had been written off the capital value of the buildings, which sum had been levied as depreciation and charged against the productions. Similarly, the capital value of the machinery had increased from £570,609 on 1 April, 1897, to £773,255 on 1 April, 1907, while £673,627 levied as depreciation had been written off the capital value. The committee regarded with suspicion the whole policy of preserving old machinery in view of emergency, or of building up a large reserve to that end. They pointed out that military requirements were constantly changing with the progress of mechanical invention, and that the only cases in which reserves were justified were those of special manufactures which could not be obtained from the trade and might be urgently required during the initial stages of a war. They held that much of the machinery held as a reserve was really surplus and should be sold or scrapped. As a result of this committee's recommendations a certain amount of surplus machinery was disposed of, the rate of depreciation on buildings was reduced from 5 per cent. to 3 per cent., and a maximum limit was fixed for annual expenditure on repairs. The proposal to fix a limit for annual expenditure on new buildings was not, however, adopted. The committee desired to fix a maximum limit to govern both the expenditure on new machinery and its repair and maintenance. The amount of money thus allocated, following upon the adoption of the report, was inadequate, and the expenditure on each machine had to form the subject of a separate request, with the result that on the outbreak of war the machinery generally was in a bad state of repair, unfit to stand the strain imposed by demands created by the war. The recommendations of this report had not

been fully acted upon by the outbreak of war, and some of the condemned machinery did valuable service throughout the war. The concentration of shops recommended by the committee effected little, the same shops in some cases having to be rebuilt on the same site after the outbreak of war.

The percentage of the total production of armaments produced at the Ordnance Factories showed a marked decrease between 1909 and 1913 in the case of every kind of store. The size of the nucleus establishment was perforce based upon the estimated requirements. It provided for a moderate expansion commensurate with the demands likely to be made. It was, accordingly, inadequate to meet the vast expansion actually required in August, 1914. The measure of this expansion may be realised from the fact that before the middle of September, the Ordnance Factories had done more work for the Navy than the Board of Admiralty had communicated to them as required for the first six months of a war in which all the land and sea forces of the Empire were engaged. The inconvenient lay-out of the factories was one of the most serious factors in hindering rapid expansion. The Arsenal had been built up by degrees for generations back. Some of the shops were very old, badly lighted and ill ventilated. The three factories had been originally kept distinct, but insufficient space had been allowed for their expansion within their own boundaries, and encroachment had been made by one upon another. An ideal factory would, no doubt, have had a single chemical laboratory, testing house, and gauge and tool factory, but Woolwich had many of them scattered throughout its area. The efficient siteing of new shops built during the war became difficult if not impossible, and the congestion, which increased as the war went on, made efficient and economical management more and more difficult. Similarly neither the site of the Royal Gunpowder Factory at Waltham nor that of the Royal Small Arms Factory at Enfield was adapted for any considerable extension.

Various legacies of the past had, in fact, placed the management of the Ordnance Factories at a serious disadvantage in meeting the heavy demands made upon them at the outbreak of war. The lay-out of all the factories prevented expansion on well-ordered lines, and the lay-out at Woolwich involved traffic congestion directly mobilisation began. Much of the machinery was known to be out of date and in a bad state of repair. The staff was not adequate for the efficient management of the factories when working at their maximum capacity, and insufficient provision had been made for a reserve of foremen. The exceptionally favourable conditions already promised to employees militated against economical production, and concessions made during the course of the war had a similar effect.[1] The established routine in regard to accounting was not the best suited to act as a check upon contractors' costs or for comparison with those of the new national factories.

As compared with the Ordnance Factories, the Royal Aircraft Factory at South Farnborough is a very modern establishment.

[1] See below, p. 14.

The factory developed from the sheds and workshops of the Balloon Factory built at South Farnborough in 1905. It was, therefore, free from many of the difficulties which beset the Ordnance Factories. Its layout was modern and convenient. On the outbreak of war a large proportion of the spares for the Royal Flying Corps was being supplied and stored by the factory; but arrangements had already been made to start at Pinehurst the Aeronautical Ordnance Department, a Military Stores Department which began in August, 1914, to take over from the factory the duty of holding stores for issue to the Royal Flying Corps, with the exception of special items such as instruments. Aircraft Inspection had been decentralised before the war. Detailed inspection took place at contractors' works, and though final erection and flight tests were at first carried out at Farnborough, this part of the work was also decentralised early in 1915. Thus no problems of traffic congestion arose there on account of the demands of different departments on the means of transport. From the outset Farnborough was under civilian management. The necessity for the military element in management did not arise in the case of aircraft supply, which was essentially a civilian occupation before the war, and the interests of the users were sufficiently safeguarded by the direct responsibility of the Director General of Military Aeronautics for the management of the factories.

III. Labour Conditions.

Since 1903 the close connection between education and efficiency in such an establishment as the Arsenal had been clearly recognised, and a great deal had been done, by reducing the hours of labour and providing access to technical information, in raising the general educational standard of the workmen. The managerial staff was formed into an upper and lower division, and the upper division was recruited by the annual appointment of three "supervisors" chosen by an examination which aimed at securing men of higher qualifications, preferably of the University type, who, after obtaining degrees, came to the Arsenal for workshop training. At the same time the education of the trade lads (premium apprentices) was systematised and improved and promotion made to depend considerably on good educational reports. A reference library and reading room properly equipped with modern technical literature were opened free to all employees.

Shortly before the outbreak of war the Chief Superintendent was ordered to cut down all staff to an absolute minimum, and the shop staff was reduced so low that it was barely possible to carry on even in peace time. A further rule necessitated the discharge of lads on reaching the age of 18, unless it was then certain that work would be available for them at the age of 21, and the substitution of men who would otherwise be discharged on reduction. Thus the Arsenal was forced to get rid of most of the young men they had been training, including half the trade lads, who were relied on for future foremen. One consequence was that men were engaged upon jobs which could have been done by boys or women. On the outbreak of war great difficulty was experienced in getting young men with the necessary

trade and technical training. Such men were in great demand in the armament firms, and the limited prospects of promotion at Woolwich sent the best men to the trade firms.

Labour regulations and conditions at Woolwich were quite different from those existing in any other factory in the kingdom. The rates of wages were based on London district rates, but the normal working hours were less. A large part of the work was done as piece work. Prices before the war had been based on small outputs, and it was found that when output increased, these rates were very high owing to the skill acquired by repetition ; but an express understanding of many years' standing that rates should not be cut was solemnly ratified by the Minister of Munitions in 1915, and prevented any alteration of these rates except by altering the method of manufacture. The position of the Woolwich factories in regard to dilution was also unique. The use of female labour at the Arsenal had been stopped, as mentioned above, many years before the war. The prohibition remained in force until August, 1915. Dilution of skilled labour either by women or unskilled men was strenuously resisted by the skilled employees of the Arsenal, and was accompanied by great delay. An arrangement was made in February, 1916, between the management and the Amalgamated Society of Engineers whereby in each group of shops the skilled workmen chose representatives to consult with the manager as to the description of work on which skilled labour might temporarily be displaced by semi-skilled or unskilled labour, either male or female. This arrangement was to begin when all substitutes under the scheme for the dilution of skilled labour had been removed from the skilled work to which they had been advanced. The effect of this arrangement was greatly prejudiced by an undertaking given by the Chief Superintendent that, since the scarcity of skilled labour was the only reason adduced for its dilution, he would remove the unskilled men who had been taken on if skilled men could be brought in from outside sources. Great and fairly successful efforts were made by the Amalgamated Society of Engineers to fulfil this condition, with the result that dilution was seriously retarded, and skilled labour unjustifiably hoarded. Any skilled man set free in one factory could practically claim that room should be found for him in another where dilutees were working. The progress in dilution was specially disappointing in the Small Arms Ammunition Factories.[1] The other two Ordnance Factories, unhampered by the restrictions which existed at Woolwich, experienced less difficulty in diluting labour. The Royal Gunpowder Factory eventually employed almost as many women as men. The Royal Small Arms Factory was prevented from introducing a large proportion of inexperienced labour only by the special character of the work. The Royal Aircraft Factory, also unhampered by precedent, introduced female labour at an exceptionally early stage in the war.

[1] The percentage of women employed on skilled work in Small Arms Ammunition Factories was as follows :—

	December, 1917.	*July*, 1918.
Messrs Kynoch	32%	29%
G.C.F. No. 1.	70	64
Woolwich	5	25

IV. Finance and Accounting.

Before the votes for the separate factories were amalgamated in 1888, the manufacturing accounts submitted by each factory were mere statistical statements which did not form the basis of any charges against army or navy funds. Account was kept of the wages of men employed, and of material directly consumed on an order. To this was added a proportion of indirect expenditure, the total indirect expenditure being levied as a percentage on direct labour charged against each order in the cost ledger of each department. These three items formed balance sheet No. 1, in the accounts of the manufacturing departments annually presented to Parliament. As, however, this balance sheet took no account of depreciation or of capital expenditure, it did not allow of fair comparison between the cost of articles manufactured by the Government, and of articles purchased from the trade, and a second form of account was evolved in 1864, called balance sheet No. 2, which included a charge to cover estimated depreciation of buildings and machinery and interest on invested and working capital, viz., depreciation on buildings 5 per cent., on machinery 10 per cent., and interest on invested capital 3½ per cent., and on working capital (taken at one-fifth annual expenditure) 3½ per cent. In the annual account the cost of each article was calculated both on No. 1 and No. 2 balance sheets.

Lord Morley's committee criticised the system of checking wages, which seemed too elaborate in view of the fact that it was impossible to apportion the indirect expenditure accurately between the different orders. They reported that it might be simplified with advantage, but suggested no definite change. This system was still in operation when the accounts of the factories were investigated by the experts who reported to Lord Randolph Churchill's Select Committee on Army Estimates in 1887-8. This report advised no change in the system, on the ground that it was simple and, at the same time, sufficiently accurate for the purpose of the Ordnance Factories as then circumstanced. In 1888, however, a change was effected in the method of Parliamentary provision, by the introduction of a vote for the Ordnance Factories as a whole, instead of a separate vote for each, and in 1890 the whole system of accounts was overhauled and centralised. By this means there were obtained uniformity of system, facility of preparation of Parliamentary accounts, economy of staff and control of expenditure. The system provided the Chief Superintendent of Ordnance Factories with a means of control over factory operations, while individual superintendents were allowed free access to the books, and were encouraged to make all possible use of it. The cost accounts of the factories, as far as labour was concerned, were based on the records made by a staff of "work-takers," who were the immediate subordinates of the officer in charge of the works accounts branch of the central office, not, as previously, subordinate to the superintendents of factories. By this system a reliable account was secured of work done and wages earned. Depreciation on machinery as well as cost of repairs, engine power and other current expenditure on plant was charged to indirect expenditure and ultimately distributed

as a percentage on the wages debited to orders in the cost ledgers, much in the same way as was the case in 1887. Exceptions to this rule were the Gun Factory, where it had long been recognised that the distribution of these charges as a uniform percentage on all classes of work would fail to give reliable costs for guns varying in weight from a few hundredweight to many tons, and the small arms factory then existing at Birmingham, which was divided into two branches for manufacture and repair of arms, the use of machinery being almost exclusively confined to the manufacturing branch. Special arrangements for meeting these cases had been introduced into the accounts, the work of the Gun Factory being divided into three classes, heavy, medium and light, and each class bearing an appropriate special percentage on materials and labour for "machinery charges," while at Birmingham the depreciation and other charges for machinery were practically all thrown upon the manufacturing orders. Such exceptions showed that the old simple method was no longer adequate to the altered conditions of manufacture, with the wide differences between the cost and working expenses of the different types of machinery, and the increased importance attaching to comparisons between factory and contract prices for similar stores.

Under this new system no charge for interest appeared in the accounts. As the actual cost of work done as shown in the public accounts was recovered from Army, Navy and India funds and credited to the account of the Ordnance Factory vote, it followed that if charges for interest were included in the cost, sums would be credited to the vote which had not been expended out of it, and the account would exhibit an annual surplus to the extent of such interest, contrary to its general intention. Since the main object of the cost accounts was to show the average price of each production for the financial year, separate accounts were not kept for different orders for the same production, so that no account could be closed until the end of the year. Since there was practically continuous manufacture of a large number of articles, it was impossible to obtain the actual cost without taking stock of articles in process of manufacture on each order. This was done at the end of each financial year, and the total expenditure on each order during the year reduced by the value of semi-manufactures at the end and increased by the value of semi-manufactures at the beginning, gave the cost of the net production on the order. Differences in cost of production occurring during the year which might have been of importance for purposes of supervision were not shown.

An enquiry was held into the system of accounting in 1901–02. Mr. H. F. Donaldson, then Chief Mechanical Engineer at Woolwich, a civil engineer of large experience, attached great value to a system of cost keeping which should be of assistance for administrative purposes. To attain this it would be necessary to handle each week's expenditure at once and make returns to those responsible within a week, so that immediate investigation could be made into any points requiring examination. This point had not been lost sight of when framing the system in 1890, and one of the first enquiries made when

the works accounts branch was constituted was as to the class and form of information with which the superintendents would desire to be furnished. This produced no suggestions, and the impression was conveyed that the superintendents did not care to have any such information. No further steps were taken, but the details were always obtainable if desired, and Mr. Donaldson thought that the value of semi-manufactures could be assessed weekly by work-takers and foremen, thus allowing for the production of weekly costs. The committee of inquiry was, however, mainly led by the report of Mr. Morland, an accountant, who, after making, at the committee's request, an independent comparison of the systems of accounts at the factories and at various armament firms, summed up the result of his examination as follows :—

> "Speaking generally, ... the system of cost accounting at Woolwich appears as well adapted to obtain the results required as that in use at any of the works visited. These results differ in character from those of commercial houses, owing to the absence of profit considerations and to the requirements of Parliamentary returns."

The committee, therefore, contented itself with recommending the adoption of the more accurate systems of allocating machinery charges, in common commercial use, by which the work done at each machine bears an appropriate charge estimated to cover depreciation on that machine, cost of its maintenance and the power it consumes. The committee considered the difficulty of the omission of charges for interest in obtaining comparisons between Ordnance Factory and contract prices, but came to the conclusion that such comparisons would not be facilitated, but rather the reverse, unless the sums included in the factory accounts for interest were calculated at a commercial rate of interest on a figure representing the commercial value of the factories. It did not appear that a Government rate of interest calculated on the capital value of the factories as shown in their books would fulfil this condition. Since it would always be necessary to make a considerable allowance in comparing factory prices with contract prices, for elements which enter into the one and not into the other, it appeared that no useful purpose would be served by incorporating charges for interest into the Ordnance Factory accounts. They reported that, subject to the adoption of the improved system of allocating machinery charges, the factory accounts were kept on sound principles and exhibited correctly the cost to the country of the production of the factories; but it was obvious that these prices could not be compared with the selling prices of contractors. Besides the element of net profit and interest on capital there were other elements of expenditure which contractors incurred, which did not exist or existed only in a minor degree in Government factories. Such were the cost of advertising and obtaining orders, the cost of protecting and working out inventions, insurance, provision for bad debts and slack times, and risk of loss through changes in type of warlike stores. The allowance to be made for these elements

was essentially speculative, so that no fixed percentage of difference between factory and trade prices could be laid down. It appeared that nothing was to be gained by departing from the basis of actual expenditure on which the Ordnance Factory cost prices then rested. The rates published in the *Priced Vocabulary of Stores* were in a large number of cases based on Ordnance Factory cost prices, and these rates were often wrongly supposed to represent full and fair selling prices, to the detriment of British manufacturers when dealing with customers in other countries. It was, therefore, recommended that words should be inserted, both in the Woolwich accounts and in the vocabularies, showing that there were certain trade charges not included in the Woolwich cost of production. As a result the following words were added: "prices shown in these accounts do not include rent of land, interest on capital or other trade charges, and risks not incurred in Government manufacture." When these words came to the notice of the Committee on Public Accounts they insisted on the further additions: "but on the other hand include charges for depreciation and upkeep of unused buildings and machinery, maintained with a view to expansion, and cost of care and custody of Imperial stock stores." These words seemed very essential in view of the fact that, in some instances, Woolwich had building and plant five times as large as were required for current work, maintained simply with a view to expansion in time of war.

From this time the possible use of costs in assisting administration appears to have been overlooked. A committee enquiring into the Royal Factories in 1907 were chiefly concerned by the number of qualifications and corrections necessary before comparisons could be made with other trade prices. They were doubtful whether the voluminous details contained in the accounts were worth the trouble and expense incurred in their production, and thought the publication of detailed prices in their existing form undesirable.

Parliamentary action thus tended to militate against any revision of the existing system of costing, which remained unaltered until the outbreak of war. It was the practice, however, to extract and furnish to the managers periodical statistics of shop non-production and certain other classes of indirect expenditure within their control.

After the outbreak of war expansion was the primary consideration; the staff of the cost accounting branch was depleted in order to strengthen the far more vital stores and wages branches and the Pay Office. Ascertaining costs became a secondary consideration, and when at the end of the financial year it was found impossible to close for stocktaking, the whole basis of the system gave way and the account could not be built up in the correct form. The question was referred to the Treasury, who intimated that all that they wanted during the progress of the war was an interim statement of expenditure with an approximate division into charges against the Army, the Navy, India and the various colonies served, but that they expected that a complete stock should be taken at the close of the financial year succeeding the termination of the war, and one complete account produced showing the actual cost of production of all the articles

manufactured during the war. In pursuance of this ruling the Woolwich accounts section booked expenditure currently against the several orders, and by estimating could arrive at the approximate cost, but owing to the delay in obtaining prices of materials, accurate costing was out of the question. Various information was, however, supplied to the superintendents at their request, during the war, such as weekly labour costs, machinery rates, day work and tool percentages, and non-production percentage, or the estimated cost of any particular article periodically so that the variation of price could be watched. Any periodic estimate of prices of all articles was out of the question on account of the expense and the inadequacy of the staff. On costs and non-production charges were, however, watched separately and records were sent to the factories. The weekly report of the work-takers also furnished the Chief Superintendent with a means of detecting any abnormal prices or unusual development of costs in the factories. The Controller of Small Arms Ammunition Factories watched efficiency indirectly by records obtained in the shops, relating to output, machine efficiency, stores consumption, tool consumption and numbers employed. Similarly the Controller of the Filling Factory watched efficiency by checking the quantities of material used with that estimated for, by watching output and by watching rejections and tool consumption. Ultimately, however, the preparation of a detailed production account for the whole period of the war was abandoned on the ground that the information would be of little use for comparison with pre-war rates or future peace-time costs.

Weekly progress returns were instituted at the Factories in April, 1916. The statistical records of output posted in the shops aroused great interest among the men and were believed to be the cause of a definite improvement in efficiency, not only on account of their effect on the men, but because they enabled the management to detect at once the cause of any drop in output.

At about this time (January, 1916) the Superintendent of Waltham and Enfield expressed a desire for the transfer of the accounts of his factories from the central office at Woolwich to his own office, in order that he might extract costs. He was, however, discouraged by the Ministry (E.M. 4.) on the ground that it was a mistake to undertake any complication or increase of work at a time of such pressure, when all information required could be reasonably well obtained by existing machinery, and that the matter was not one of urgent practical necessity in connection with output during such abnormal times. At a later date, Mr. Eric Geddes, in enquiring into the organisation of the factories as it stood when the Ministry assumed control, recommended that in view of the temporary nature of Ministry control, the costing system and accounts should not be disturbed. It must also be remembered that during the war considerable fluctuations in current costs would have excited no particular remark, since "rush" jobs entailing overtime and night work were of common occurrence.

The evolution of a system of costing over short periods, giving comparative statistical information to the management, and the establishment of such systems in the new national factories gave rise to

a demand for similar costing figures from Woolwich for purposes of comparison. At the end of 1917 the question was discussed within the Ministry of the desirability of reorganising the system at Woolwich in order to obtain results comparable with Ministry costs. Two experienced accountants by whom the subject was investigated were unanimous in thinking that the advantages of modernising the system would not compensate for the risks of temporary disorganisation and reduced production that would almost certainly have to be faced. The existing system could have been adapted to provide monthly costs of production had it been possible to take stock in the shops at the end of each month, but it was clearly inadvisable to place on the foremen or worktakers in war time such an additional burden of work, and the matter was dropped. The opinion of one of the accountants may here be quoted :—

> "I should like to express the view that under war conditions our principal aim should be to do nothing that will hinder methods that already work satisfactorily and also to avoid the pitfall—not uncommon to professional accountants—of allowing one's desire for ideal systems of safeguard and control to obscure the vital need for simplicity co-existent with a high standard of efficient production."

In the summer of 1918, however, the manufacture of munitions had developed to such an extent that the consideration of questions of economy and efficiency of production became possible and the absence of an adequate current costing system at Woolwich became the subject of much adverse criticism. On the one hand, the Ministry was anxious to obtain the costs of manufacture at Woolwich along lines exactly similar to those adopted in the new national factories in order to judge of economy in allocating capacity, and to check contractors' prices. On the other, the management of the Ordnance Factories, even had it not been fully occupied in producing the munitions so urgently required, was tied by past legislation to a system which differed in form from that established by the Ministry of Munitions, and could only be changed by the authority of the Treasury with the concurrence of the Auditor General and Public Accounts Committee. Nor did they, at that time, conceive it to be possible to engraft the Ministry's system upon the existing method of accounting without seriously increasing expense. Some considerable time after the conclusion of hostilities steps were, however, taken towards introducing a system of cost accounting, which, by the use of up-to-date methods of calculation, neither increased establishment expenses nor interfered with the accounts prepared for the Public Accounts Committee.

Both the historical development and the functions of the Ordnance Factories tended to increase the costs of production and to render difficult any comparison of costs between them and those of other armament producers. Economy was not consistent with the peace-time conditions which entailed the employment of highly skilled men

in comparatively unskilled work, and the upkeep of a large amount of non-productive machinery, all of which were imposed upon the factories by their character as a war reserve. These factors tended also to hinder the subsidiary function of the factories as a check on costs of production; although many prices, and particularly those of rifles and small arms ammunition, had been regulated by the Ordnance Factories' costs right up to the outbreak of war. Even before 1900, when the supreme importance of the factories as a war reserve became fully recognised, Woolwich costs were of doubtful utility for comparison with the prices charged by the trade on account of the differences in the bases on which they were calculated; after that time comparison became still more difficult. As explained above, Woolwich costs were in 1886 produced in two forms with a view to affording figures comparable with trade results, but successive committees pointed out the impracticability of comparison with trade costs. By 1909 high charges for certain productions of the Ordnance Factories became the subject of investigation by a committee. They appeared to be due, amongst other causes, to excessive capital and current expenditure caused by the provision of adequate war reserves, high rate of depreciation and heavy charges for maintenance of buildings and machinery. The difficulty of effecting reductions in the upper grades of the establishment, commensurate with the very considerable decrease in output and direct labour, also had a very distinct effect in increasing costs. The committee found that the factory superintendents were not responsible for the expenditure on maintenance of buildings, this being controlled by the Superintendent of Building Works, but that they had direct control over the expenditure on maintenance of machinery, subject to the approval of the Chief Superintendent for services over £50. They thought this system tended to the repairing or replacing of machinery, without adequate consideration of the question as to which course was really the most desirable from the point of view of economic production. There was reason to believe that the primary consideration with the factory superintendents was to secure efficient workshops and to reduce the amount expended on labour, while the question of keeping down the actual cost of their productions tended to become a secondary consideration. This may have been an outcome of the partial centralisation which removed the accounts from the responsibility of the superintendents, while leaving them considerable independence in other directions, a tendency which had been pointed out in 1902.

The site of Woolwich, at such a distance from the coal producing areas, and its bad layout also tended to increase costs. The wide separation of certain units which should have been closely associated led to a large amount of haulage of components between the various shops, and intensified the congestion already existing owing to the defective internal railway communication. The shops were in many cases overcrowded, due to war emergency installation of extra machinery without time being available to reconstruct the internal and external shop communication. The distance between the shops led to the multiplication of tool shops, All these conditions affected efficiency

and increased costs. At the end of the war it was stated that in the Royal Gun Factory, the only shops in which economical production was possible were the new gun machine shop, the new treating and annealing shops and the two press shops. There was a considerable amount of good new machinery in the other shops, but this had been placed in the available floor space between existing machines and the layout was unsatisfactory. The obsolete machinery of pre-war times which was still in use, was uneconomical in output and wasteful in power. In the Carriage Department the main shop was hopelessly congested, and no good means existed of handling materials and jobs to and from the railway. The sight-shop also was old-fashioned and congested. Similarly, the gradual growth of the Royal Gunpowder Factory along a narrow strip of land increased the haulage of materials from unit to unit, and thus rendered the position of the factory, as a standard of economical production, quite useless.

One of the principal factors in raising Woolwich costs of production and rendering difficult any comparison with trade prices was the multifarious nature of the work. The effects are almost impossible to gauge, but even in 1902 the jobbing work of all sorts, which was a feature of Woolwich, was recognised as differentiating it, as regards economical production, from an ordinary armament firm conducted on commercial principles. Most factories had a fairly straight run of work which could be arranged in the best possible way for production, but Woolwich programmes were subject to constant changes, and apart from the ensuing disorganisation the necessary alteration in layout of machinery accounted for considerable expenditure. A building put up for a certain purpose might, when converted to some other manufacture, need considerable alteration, as happened in the case of buildings laid out for filling Q.F. ammunition, which were afterwards used for filling fuses. The preparation of shops for new classes of work sometimes involved complete cleaning down or rearrangement of plant as, for instance, when a change was made to black powder filling, from the filling of phosphorus smoke containers into 18-pdr. shell. The costs at the filling factories were very much increased by the constant change of programme and great variety of work, the weekly programme frequently containing 300 separate items, while, as no other factories worked under similar conditions, fair comparison was impossible.

The cost of all the experimental work done in the Ordnance Factories was charged to production, while it also had an effect in increasing cost by interrupting supply work. The same factor operated at Farnborough, a machine being designed and drawings made to govern the production of some thousands of machines while the whole cost was charged to the few machines actually built at Farnborough.

Small arms ammunition manufacture at Woolwich was particularly affected by a combination of these factors increasing cost, though owing to the repetitive nature of the work it was often regarded as providing a suitable test for Woolwich prices compared with those of

other producers. The rolling mills were exceptionally expensive to run, owing to the fact that the shop had been originally built as a store for horseshoes, and was broken up by the iron pillars of the roof. There was no overhead crane and the relative positions of the annealing furnaces and mills were very awkward. In consequence the handling of material was very great and the labour required, though not of high skill, was of physically high standard, and therefore expensive. In the work of drawing and stamping, boys had been replaced by women at higher rates. Girl labour would have been preferable but was inadmissible on account of the night shift. Tool setting was, for the reasons explained above,[1] done by skilled men or by women at skilled rates, though all such work was done in the Birmingham area by semi-skilled labour. In one of the shops, inspection work which could well have been performed by young girls, was done by disabled men at men's rates. The shops in this group were so remote from each other that each had to have its own tool shop, and traffic between them was very wasteful. The kinds of work in progress at these shops were very numerous, forty different types at times being dealt with. The orders were frequently very sudden and often very small. Woolwich was also handicapped in this respect by the pre-war policy of excluding female labour and paying high piecework prices, a policy which could not be altered without breaking Government pledges. Overtime allowances at Woolwich were exceptionally large, while at the National Cartridge Factories and at the largest firms these allowances were smaller than those usually accepted in the engineering trade. The heavy oncost due to schemes of pensions and gratuities, hospital and medical attendance, etc., all of which were part of the factory system, tended to increase the cost of production, although in some instances an apparently uneconomical practice ultimately resulted in a gain to the Exchequer. Thus, for instance, the practice of giving prospective gratuities and current holidays with pay was counterbalanced by a reduction of 1s. in the £ below the district rates, which governed overtime as well, and converted an apparent loss into a distinct gain, when the men concerned were working 84 hours per week.

The position at Woolwich throughout the war has been aptly summarised as follows :—

> "The work Woolwich has undertaken has been largely of a character too unpopular for the private manufacturer to consider, or of such an experimental character as to preclude any opportunity for economical production being given to the management . . . . It is clear that the orders which Woolwich has executed have been nearly always in the nature of either experimental or panic demands, the essence of these contracts being not economical production but to bring the experiments to quick finality and speedy delivery of the goods to the fighting line, regardless of cost."

[1] See above, p. 14.

V. Achievements during the War.

(a) Production.

Immediately on the declaration of war, expansion took place at all the Royal Ordnance Factories by employing additional staff to work the shops to their full capacity. Night shifts and overtime work were introduced into all departments. It was soon found that this expansion was insufficient to meet the heavy demands made upon the factories, and that actual extension to both plant and buildings would also be required.

The actual area of extensions which took place in the Woolwich Factories during the war in the several departments was 1,520,572 sq. ft. in the Royal Laboratory, 588,342 sq. ft. in the Carriage Department and 273,302 in the Royal Gun Factory, the total for the whole Arsenal being 3,433,609 sq. ft. The extensions to Waltham Abbey were strictly limited by local conditions, the unfavourable layout, due to the piecemeal growth of the factory, and the obvious risks of concentrating dangerous operations in a district peculiarly subject to air-raids. Certain extensions were made to the cordite plant during 1914 and 1915; but the construction of the enormous state factory at Gretna thereafter lessened the need for expanding the cordite plant. Tetryl plant was increased in the autumn of 1915, but this manufacture was subject to peculiar danger. Much of the purification plant was destroyed by fire, and ultimately the output from the Ordnance Factory was entirely replaced by the new plant at Queensferry.

Considerable extensions were made at Enfield, and included new shops of practically every kind required for small arms manufacture; but here again local conditions strictly limited expansion, and projects for doubling the capacity of the factory were abandoned on this score.

Of the many activities of the Royal Factories during the war, it is possible to notice only a few of the most important which illustrate their success or failure in fulfilling their functions as a war reserve. As regards the Woolwich factories, the work of the filling factories between August, 1914, and December, 1915, is of outstanding importance. The filling of the entire requirement of high explosive shell for the land service and from 40 to 50 per cent. of the naval requirements was carried out at Woolwich when war broke out. The remainder of the filling of naval shells was done at the Naval Ordnance Depots, but these soon became so much occupied with repair work that little filling could be done there, and the Admiralty became more and more dependent on Woolwich capacity. Woolwich also undertook the filling, assembling and finishing of large quantities of empty shell produced by the trade, and did the greater proportion of the filling of components and fuses, though a few fuses and minor components required by the land service were filled by the trade. At the beginning of the war picric acid was the standard high explosive for all classes of shell, and reliance was placed on Woolwich alone for melt filling with this explosive. When T.N.T. was adopted

in October, 1914, as a substitute for lyddite in the larger shells it was possible to adapt the melt plant to T.N.T. filling, and Woolwich continued to do all high explosive filling until the following spring.

Another very valuable aspect of Woolwich work during the war was the production of many special or experimental stores required in small quantities only. Of particular importance was the work of the Royal Laboratory in producing special small arm ammunition. The supply and design of this ammunition was one of the most difficult problems of the war, and it was largely due to the untiring efforts of the Royal Laboratory that the technical difficulties were overcome and supplies placed on a satisfactory footing. In the early days of the war Woolwich supplied the only available tracer and armour piercing ammunition. The early types proved unsuited to meet the demands of the services, and much research, the greater part of which was carried out at the Royal Laboratory, was necessary before satisfactory types were evolved. Owing to the numerous manufacturing difficulties which were encountered in producing these stores, supplies from trade sources were unreliable, and Woolwich had to undertake the production of all types, the Royal Laboratory output on many occasions saving the situation when trade deliveries failed.

For certain stores the Ordnance Factories were the only source of supply for the first months of the war. The only grenade in use in the Army at the outbreak of war was the Royal Laboratory percussion grenade which was manufactured solely at the Laboratory until June, 1915, and even after that time Woolwich still remained the sole maker and filler of the detonator.

Though before the war manufacturers of warlike stores had supplied their own shop gauges, Woolwich alone manufactured inspection gauges. After the outbreak of war, though output from the Ordnance Factories increased from 200 to 300 per cent., Woolwich was unable to produce fast enough to meet the demand, and by the middle of 1915 the requirement for these gauges had increased far beyond the capacity of Woolwich to supply them. Contracts were being very widely placed by Chief Inspector, Woolwich, before the formation of the Gauge Department of the Ministry. After gauge supply had been organised by this department, Woolwich still continued to supply all its own gauges and a considerable proportion of those required by the department.

Though in August, 1914, the capacity of the Ordnance Factories included the production of nearly every warlike store then recognised, there was one exception which led to somewhat serious results. For supplies of picric acid before the war entire reliance was placed on the trade. On the outbreak of war the services were depending on picric acid as the bursting charge for all high explosive shell. A reserve of 150,000 lbs. was held at the Ordnance Factories on behalf of the Navy, but there was no special stock kept to fill the small requirements of the Army. It had been assumed that large quantities would be forthcoming from the trade on very short notice, but immediately on

the outbreak of war it was found that the trade was incapable of carrying out the part assigned to it. By October, 1914, the increased use of high explosive made it necessary to increase the supply by erecting national plant, but the work of the Ordnance Factories was already so congested that the Chief Superintendent was unwilling to undertake the organisation of high explosive manufacture, and the work was assigned in January, 1915, to a special section of the Directorate of Artillery, which later became the Explosive Supply Department. It thus came about that neither picric acid nor T.N.T., which began to displace picric acid as the standard high explosive at about this time, were ever manufactured at Waltham Abbey, though plant for the production of T.N.T. which had been set up, on a semi-industrial scale, in the Research Department, Woolwich, for investigating manufacturing processes in October, 1914, was temporarily regarded as an important source of supply. For similar reasons the manufacture of the new ammonium nitrate mixtures was not undertaken at the Royal Gunpowder Factory. In addition to the actual shortage in supply caused by reliance on the trade for high explosives, delay in starting up new sources of supply was occasioned because the new supply department had no source of exact and practical knowledge as to manufacture.

Some of the new weapons evolved during the war were never manufactured at Woolwich owing to the fact that they could be more conveniently produced elsewhere. Such were tanks, mechanical transport and certain naval stores, while the assembling of chemical shell was only undertaken for a very short period.

A somewhat similar state of affairs to that produced by the failure to manufacture picric acid at the Ordnance Factories before the war was brought about in aircraft supply by the policy of depending on the trade for supplies of benzyl alcohol, an important ingredient of dope. It was the practice of the Aircraft Factory to purchase it in the market as a raw material, and it was not until war broke out that it was discovered that it was a German monopoly. Its preparation was immediately undertaken at Farnborough, but it was some time before manufacture on a large scale became possible.

Throughout the war both Woolwich and Farnborough were called upon to act as a balancing capacity to make good failures in deliveries from other sources, or to meet sudden urgent demands from the front. During the first two years of the war this adjusting process was a very imperative and frequent one at Woolwich, the Chief Superintendent being advised direct from the War Office almost daily as to which articles to push forward and which to defer to make way for them. Woolwich was depended on equally by the Ministry of Munitions in this way, and there seems to have been complete unanimity as to the efficient manner in which the Ordnance Factories responded to demands thus made upon them. In meeting these "rush" demands Woolwich was greatly assisted by its proximity to the Inspection Department, enabling it to obtain drawings at a few minutes' notice.

Notable instances occurred in the autumn of 1917, when the filling and assembling shops worked continuously throughout enemy air raids, to assemble anti-aircraft ammunition required for the barrage fire for the defence of London, and again in March, 1918, when the same was done, to meet the demands of the Army for ammunition during the German offensive.

There can be no doubt that Woolwich fulfilled its promises of production in a way that no other supplier did, and when it is remembered that normal output of ammunition was constantly disturbed by urgent demands for output of special stores, and that the attention of the expert staff was largely engrossed in the development of design, the steady output of small arms ammunition given by Woolwich tends to negative the charge of bad organisation. On the other hand, labour costs at Woolwich were undoubtedly high, owing, largely, to circumstances over which the management had no control, and it is remarkable that one of the features most criticised, viz., the adoption of a normal 48-hour week was afterwards generally accepted throughout the country.

The Ordnance Factories were sometimes accused of undue deliberation in accepting new processes. The fact that Woolwich was an adjusting factory, liable to constant changes of programme without notice, made some proposals which were generally accepted as improvements, inapplicable to it. Such developments could only be justified and carried out in works where it was a condition that an unlimited demand could be assured over a long period for an article or type. These conditions never obtained at Woolwich, either in peace or war. On the other hand, Woolwich did in many instances adopt labour-saving devices and improved processes from other factories, but the general practice was to abstain from changes in process or machinery without adequate trial, and this position was justified in many cases by failure of machines or processes which gave early promise of success, as in the case of a machine for filling primers used at Cardonald. There can be little doubt, however, that munition supply would have been benefited by a greater measure of freedom in exchange of views between the Ordnance Factories and the newly established national factories.

(b) DESIGN AND EXPERIMENT.

Owing to war conditions the demand both for supply and design work at Woolwich increased very greatly during the early years of the war, and there was a tendency for supply to take precedence over experimental work. At the beginning of 1916 it was suggested by General Bland, the Chairman of the Ordnance Committee, that in order to meet this difficulty the staff connected with experimental work at the factories should be entirely separated from the staff connected with output, and from all other routine duties in the Arsenal. A Superintendent of Design was appointed to watch the

interests of design and experimental work as opposed to output and supply. He took over all the duties of the Chief Superintendent with regard to design, and was an *ex-officio* member of the Ordnance Committee. He had a staff of designing officers and had control of the three departmental drawing offices, and was responsible for the manufacture of experimental stores. The suggestion was made that the Superintendent of Design should be in London with his staff, but on due consideration it was decided that it was most essential that the drawing offices should be in close touch with manufacture so that officers responsible for the drawings could see the original stores being made and alter design, if necessary, to facilitate workmanship during the initial manufacture of trial stores.

The advisability of trying out all stores thoroughly and placing them on a manufacturing basis before ordering from the trade was a well-defined policy at Woolwich, for it was held that initial delays which might occur through the necessity for careful tests, were justified by the ultimate economy in eliminating alterations during manufacture. The exigencies of war-time production not infrequently prevented strict adherence to this policy, but it was adopted where practicable and sometimes drew upon the Arsenal accusations of an obstructionist tendency with regard to designs initiated elsewhere. Instances of this policy occur in the development of the supply of trench warfare stores. From October, 1914, to June, 1915, the Ordnance Factory and Messrs. Vickers were the only producers of trench mortars. Manufacture of the 2-in. trench mortar, which had been designed at Woolwich, was confined to the Ordnance Factory on account of defects in design which were only gradually overcome. For the same reason the 4-in. trench mortar ammunition was made at the Royal Laboratory alone until April, 1916. The congestion at Woolwich during the first six months of 1915, led the Chief Superintendent to place sub-contracts for trench warfare weapons with the trade and as these weapons became simplified, more and more reliance was placed on the trade, until by the end of 1916 all work on mortars and their ammunition had been withdrawn from Woolwich. On the same principle, the filling of smoke and star shell was undertaken at Woolwich, on the ground that it was research work and needed watching. In designing aircraft for Land Service this principle was equally well recognised, but the difficulties of carrying it out were much greater than in the case of most of the stores dealt with by the Ordnance Factories, owing to the rapidly changing requirements of performance, and the comparatively long period of trial required for aeroplanes and aero-engines.

Insufficient allowance had been made in pre-war arrangements for the expansion required in the factory drawing offices at Woolwich on the outbreak of war. There was a sudden large demand for drawings to guide the trade both for naval and military orders. The Admiralty was entirely dependent on Woolwich for drawings, and the drawing offices soon became congested, the difficulty being increased by the number of alterations required in the drawings, and by the need for

subdividing drawings in order to spread manufacture. Amendments had to be agreed between the drawing offices and the Inspection Department who sealed the drawings, and this often led to considerable delay.

Administratively the drawing offices still remained under the superintendents of the different factories, after the appointment of a Superintendent of Design, and in the Gun Factory the superintendent still initiated gun design, in which matters he had considerable experience. Design in the Carriage Department was undertaken by three of his assistants, all military officers, one of whom was a specialist in gun mountings. In the Royal Laboratory drawing office the Superintendent of Design placed a number of officers, and the Superintendent of the Royal Laboratory, whose administrative work was particularly heavy, had no responsibility for design.

As the war progressed the design of munitions became, to a certain extent, decentralised. The dependence of the Ordnance Board during the first eighteen months of the war upon Woolwich experience was very great, but the formation within the Ministry of Munitions of branches such as the Trench Warfare Research and Chemical Research Departments provided other expert advisers for the new Ordnance Committee, and decreased the responsibility of the Chief Superintendent for new designs. Already in May, 1915, the delay in obtaining drawings had caused the Admiralty to set up a drawing office at headquarters, which, while originally intended to deal with drawings, was gradually extended to include much design work of a simple character. More complicated designs and matters involving prolonged research were still referred to the Chief Superintendent and the Ordnance Committee. After the establishment of the national factories, a certain amount of research work was carried out by them. As the war progressed, a gradual division of design work took place between the Ordnance Factories and the trade. The Royal Laboratory retained its importance in shell and fuse design, owing to long experience. Experimental work on fuses was continuous : a shop specially maintained for this work was always fully occupied.

It was the province of the Director General of Munitions Design to consult the supply departments with a view to checking economy and availability of material, the object of the Superintendent of Design and the Ordnance Committee being rather to obtain the best store irrespective of cost. It seems doubtful whether the question of cost was given due consideration in Woolwich design. It has been stated that when commercial firms started making munitions they were much hampered by the unpractical nature of certain of the designs which came from the armament firms and from the Ordnance Factories. For instance, the designs would show square corners instead of corners that could be dealt with without any very conspicuous machining process. In the early days of the war some fuses, designed at Woolwich, had 14½ in. thread and were of bastard sizes, no jigs or gauges being available for their manufacture. In

this relation it should be noted that the very circumstances which made the Ordnance Factories the home of experimental manufacture, prevented any great importance from being assigned to ease of repetition work, since the factories were specially equipped to deal with small scale production to a fluid design.

One branch of design remained peculiar to Woolwich throughout the war, namely, the execution of repairs involving design work. The utility of Woolwich in this respect was very great. The Gun Factory was regarded as an expert adviser in these matters both for the Army and Navy, and this special branch of the work accounted for a large proportion of the work of the shops.

Design at the Royal Aircraft Factory, Farnborough, followed a very similar course to that at the Royal Ordnance Factories. For the first year of the war the Director of Military Aeronautics was almost entirely dependent for technical advice on the staff at Farnborough. The jealousy aroused in the trade on account of the government factory's having so considerable a voice in the approval of design led to the establishment of an independent design branch at headquarters to correspond roughly to the Ordnance Board in ordnance supply, and thus remove any suspicion that the government factory unduly influenced approval of design. The growing experience of the aircraft industry led at the end of 1915 to a division of responsibility for actual design of aircraft between the trade and the Royal Aircraft Factory, and left the latter more free to devote itself to special work involving more patient and prolonged experiment than could be entrusted to any of the firms.

In fulfilling its rôle as a source of experience Woolwich was seriously handicapped by previous political action. This aspect of the Ordnance Factories had not been entirely overlooked before the war, but no special provision had been made for carrying out the duties connected with it. The necessity for maintaining a staff in excess of the actual requirements of the minimum cadre had been clearly recognised in 1907, but the need for a certain amount of missionary work among the firms on the part of Woolwich foremen and inspectors does not appear to have been foreseen, probably for the reason that the recruiting of new firms into armament production was not at that time anticipated. After 1909 the staff was reduced to such a degree as to be unable to meet the needs of the Ordnance Factories themselves when expansion took place.

During the winter of 1914–15, when the question of extending the area of supply was becoming increasingly urgent, it was arranged that representatives of firms undertaking the manufacture of munitions were to be allowed to visit the shops, inspect the whole processes of manufacture and receive whatever information and advice they needed. This threw a great burden on the already overworked managers and foremen, and it was decided by the Chief Superintendent that these visitors should be passed through the Mechanical

Engineering Department, where a small staff was trained for the special purpose of taking visitors round the factory. Instruction sheets were also drawn up and printed, giving details of the various operations in the manufacture of 13 and 18 pdr. shrapnel and other shell and their cartridge cases. A more or less regularised procedure was then adopted under which firms were invited to send representatives to Woolwich to see actual operations, but the numbers were necessarily limited. In this way from May, 1915, to January, 1917, upwards of 1,500 visitors, representing many hundreds of firms, visited the Mechanical Engineering Department alone, while many others interested in guns and carriages went to the Gun and Carriage Department direct. While the National Filling and Projectile Factories were being established throughout the country, Woolwich did good work in instructing the managing staff in their new duties. In addition the Ordnance College at Woolwich was thrown open for their use.

The Royal Aircraft Factory was never relied upon for production in the way that the Ordnance Factories were. It was essentially a centre of research and experiment, and was not designed as a reserve of productive capacity to supply the first urgent requirements of war. Manufacture was carried only so far as to ensure that the difficulties of production had been overcome, and the factory was thus enabled to fulfil its rôle as headquarters of instruction and research far more easily than were the Ordnance Factories. Drawings to guide the manufacturer of machines of factory design were quickly forthcoming after the outbreak of war, and the inspecting staff, which was, however, independent of the factory, was already fully organised to give instruction to new contractors, though difficulty was found in increasing the staff adequately as the number of firms undertaking aircraft supply increased.

(c) REVIEW OF OUTPUT.

The best criterion of the achievements of the Ordnance Factories is perhaps to be found in a reference to the figures of their production during the war. The output of the Arsenal was large in quantity, varied in character and reliable in quality, and the striking increases in the outputs of the various stores between 1914 and 1916 are the best witness as to the manner in which the factories fulfilled the purposes for which they were designed before the war. Whilst the miscellaneous production of the factories was among the most noteworthy of their achievements, it is the most difficult to estimate by reason of its sheer diversity. Over 10,000,000 items of various kinds were produced by the Gun and Carriage Factories. The secondary stores made by the Royal Laboratory ranged from classes of which the output was less than one hundred to the various kinds of shell components, which amounted in the aggregate to nearly 31,000,000. In addition, the sum of the miscellaneous articles supplied by the

Royal Laboratory was nearly 300,000,000. The bulk output of the Ordnance Factories during the war is shown in the following table:—

BULK OUTPUT FROM THE ORDNANCE FACTORIES, AUGUST, 1914—DECEMBER, 1918.

	1914. Aug.—Dec.	1915.	1916.	1917.	1918.	Total.
Woolwich.						
Guns :—						
New	126	694	931	937	1,638	4,326
Repaired	387	921	1,137	2,079	910	5,434
Gun Carriages :—						
New	90	506	482	408	679	2,165
Repaired	158	242	152	319	346	1,217
Gun Ammunition :—						
Empty	124,600	1,219,000	1,749,600	1,536,900	1,217,300	5,847,400
Filled	233,200	2,094,400	6,810,100	6,181,400	4,591,200	19,910,300
Cartridges :—						
Filled[1], [2]	942,500	5,092,100	10,553,300	16,238,000	13,295,300	46,121,200
Fuses :—						
Empty	—	—	—	331,300	3,037,000	3,368,200
Filled[1]	219,000	2,046,100	18,231,100	22,939,500	15,815,600	59,251,400
Trench Mortars :—						
New	12	496	391	—	—	899
Repaired	—	58	4	6	—	68
Mortar Bombs ..	545	189,515	156,652	5,388	—	352,100
Small Arms Ammunition	30,223,500	286,623,400	502,394,100	531,947,200	367,625,000	1,718,813,228
Enfield.						
Rifles	63,107	253,545	413,424	618,073	659,423	2,007,572
Machine Guns	13	38	307	308	—	666
Farnborough.						
Aeroplanes	—[3]	31	155	163	133	482
Aero-Engines, Repaired	—[3]	203	559	599	949	2,310
Waltham Abbey.	*Short Tons.*	*Short Tons.*	*Short Tons.*	*Short Tons.*	*Short Tons.*	*Short Tons.*
Cordite	1,260	3,654	4,875	9,459	5,877	25,125

[1] Includes some of Woolwich Manufacture. [2] *i.e.*, complete rounds of ammunition assembled and filled. [3] No figures available.

CHAPTER II.

THE ESTABLISHMENT OF EMERGENCY FACTORIES.

I. Introductory.

Before the end of the war the country was covered by a network of state-directed factories which had come into existence with mushroom-like growth in the short space of a few years. Among these 200 industrial plants,[1] on which a capital of over £60,000,000 had been laid out, there were many privately established works which had been taken over by the Government and converted to national use under compulsory powers or by agreement. But the largest and most important individual enterprises were newly created, and had involved the erection and development of vast hives of industry on land previously unbuilt upon, the establishment of industrial dwellings, the laying out of streets and townships and the provision of all the necessary services incidental to the life of populous centres.

This sudden development sprang from a single motive—the need for fighting material. The demand for munitions had to be met at whatever sacrifice, and, like other war demands, the need grew more urgent as the range of effort widened and intensified. In particular it was the expenditure of artillery ammunition upon the Western battle-front, which assuming proportions never previously conceived, was not only the first to outgrow the capacity of existing sources of supply, but throughout the course of the war made the greatest drain on the powers of national mass production.

When war broke out the War Office looked to the Ordnance Factories in Woolwich Arsenal to carry the burden of ammunition supply, assisted by the resources of the long-established armament contractors who were familiar with work of this character. These firms in fact supplied 75 per cent. of the empty projectiles produced during the last quarter of 1914 ; but the loading and completion of these shells at this time fell almost exclusively upon the Royal Laboratory at Woolwich Arsenal. The first line of development to be pursued was the obvious one of encouraging in every way the expansion of the experienced armament works of the principal trade contractors, and the widest utilisation of their technical and specialised knowledge through sub-contract. They were urged to accept orders far in excess of their existing capacity in the hope that by sub-letting the simpler parts of the work and supervising the work of less experienced firms the immediate output would be multiplied, and at the same time the number of competent contractors would steadily widen as knowledge was diffused and experience was gained. Overseas

[1] A list of factories administered by the Ministry of Munitions, showing the order of their establishment as national factories, will be found in Vol. VIII, Part II, which also contains summarised accounts of each factory.

sources of supply were also explored and orders were placed by which their prospective capacity was called into play. Great as was the effort the result fell short of expectations, and far short of the rapidly increasing demands. First here then there it became necessary to create or organise further capacity at Government cost.

The new emergency state factories thus owed their inception not to any definite plan or policy of state monopoly but to the immediate stress of practical necessity. They came into being as additional to existing sources of supply, not in substitution for them. Throughout the war they worked side by side with trade factories, and in most cases their products were the same as those produced under contract.

Actual priority in order of time belongs to certain factories initiated during the winter of 1914–1915 for the manufacture of high explosives, the supply of which had not previously been undertaken in a national arsenal in this country. In the spring of 1915, these were followed by National Shell Factories, many of them establishments converted from other uses and organised for the supply of the lighter types of field gun ammunition, the demand for which seemed ever to grow beyond calculable limits. The new Ministry of Munitions undertook in the summer of 1915 the creation of National Projectile Factories, huge establishments erected and equipped *ab initio* for the supply of heavier types of shell the need for which was now multiplied by reason of the new programme for the equipment of the Army with heavy artillery on a greatly improved standard. Parallel with the National Projectile Factories and based on the same programme there sprang into existence National Filling Factories, establishments on a scale previously unknown in this country, a single one of which occupied an area of one square mile. Explosives factories had also to be replanned and developed in proportion.

Certain explosives factories had their origin later, but with this exception it may be said that the new national undertakings initiated and erected during the years 1915 and 1916 sufficed to carry out to the fullest extent the enlarged gun ammunition supply programme, which, as the event turned out, reached its climax in 1917, after which a limit on expansion was set by the limited availability of essential materials.

The national factory developments of 1917 and 1918 were more varied in character, and were governed less by any technical advantages anticipated from bulk output than by the ever increasing economic stringency which in these years conditioned all forms of industrial enterprise. As the commercial control exercised by the Ministry of Munitions increased in intensity by reason of the need for restricting importation and for securing the most economical allocation of materials, the position of the State as industrial producer became more and more predominant, and its command over material and over labour concentrated in its hands the power of initiation and development to an extent not previously contemplated. Many of the new departures of this later period were devised to satisfy demands the relative urgency of which had hitherto been less marked. Salvage

depots on a huge scale were required for diminishing the waste of valuable industrial materials or warlike equipment. Factories for the repair of guns, for the provision of gas warfare supplies, both offensive and defensive, and many miscellaneous establishments were also initiated or enlarged. Lastly the rapid development in aerial warfare led to the creation of a fresh series of factories pursuing an industry which may almost be said to have been non-existent when war broke out and in which there was consequently little or no private trade capacity to fall back upon, the manufacture of aero-engines and of aeroplanes.

This chapter will trace in outline the chronological development of these various undertakings established or managed by Government agency.

II. National Factory Projects before the Establishment of the Ministry of Munitions.

The almost entire lack of factories capable of supplying high explosives, together with the number of experiments which were being made as to their manufacture and the extremely technical nature of the whole industry, led to earlier and more drastic action with regard to their supply than with regard to that of any other form of munitions.

The Committee on High Explosives established in November, 1914, by the Board of Trade at the request of the Army Council, recommended the strongest measures, including the control of the whole supply of raw material for the manufacture of T.N.T., the prohibition of exports and the seizure of a factory at Rainham erected for the manufacture of butyl alcohol, which could be converted to the purification of T.N.T. Before the recommendation of the committee could be carried out it was necessary to pass Sub-Section (3) of the Defence of the Realm Consolidation Act enabling the Admiralty or the Army Council to take possession of, and use, any factory where warlike stores or articles required for their production were manufactured. The powers taken were even then regarded mainly as a reserve in order to secure maximum output. The Act passed into law on 27 November, and possession was taken of the works at Rainham the next day. Rainham was thus the first factory to be nationalised after the outbreak of war.

The Committee on High Explosives under the chairmanship of Lord Moulton acquired full executive power at the end of December, 1914, and determined on a far greater programme. It was decided to erect a large national factory for the supply of T.N.T. at Oldbury, to be planned by and be under the control of the State during the initial stages of production only. Mr. K. B. Quinan, of the Cape Explosives Company, was summoned from South Africa to supervise its construction. It was built at lightning speed and had begun production by May, 1915. During the spring of 1915, it was agreed that Messrs. Chance and Hunt, to whom the factory was to have been transferred on completion, should undertake its control as agents for the State, and not as contractors in conformity with the first intention. This factory was the great achievement in the way of a national factory which preceded the Ministry of Munitions, and if it did not

actually serve as a model for other factories, its erection indicated possibilities for further action and secured the services of Mr. Quinan, which were invaluable in the design of Queensferry and Gretna. The Committee on High Explosives began in May, 1915, to instal guncotton plant at Queensferry on behalf of the Admiralty, and shortly afterwards instituted search for a site, finally found at Gretna, for the production of propulsive explosives for the Army, but the Ministry of Munitions was responsible for the production of T.N.T. at Queensferry and for the whole layout of Gretna. Still, the policy of establishing these national factories belonged to a period preceding the formation of the Ministry.

The most notable remaining project of this period (August, 1914, to June, 1915,) was the Admiralty scheme for the Royal Naval Cordite Factory at Holton Heath. This new national factory was erected by that Department and remained under its control throughout the war. It owed its inception to a desire for departmental independence and to the unwillingness of cordite firms to enter into any agreement whereby the Department should retain possession of plant after the war, even though practically the whole cost had been borne by the State.

Another remarkable development of this period was the erection of wood distillation factories by the Office of Woods and Forests. A small state-owned acetone plant at Coleford, originally established in 1913, for utilising waste wood from the Crown Forest of Dean, was extended early in 1915, at the instance of the War Department, and supplementary factories were established at Dundee and Bideford. One contractor only was induced to erect wood distillation plant at Longparish, and this factory also was eventually nationalised (early in 1917).

Mention should also be made of the various explosives factories which were subsidised by the State and afterwards taken over as national factories. The inception of these works belonged to the early months of the war, and they were taken over after the formation of the Ministry, usually on the ground of indifferent output.[1]

In addition to the pioneer explosives factories, a second class of national factories had come into existence before the summer of 1915. These were the National Shell Factories. Placed under an unique system of management, and consisting for the most part of existing premises acquired and equipped during 1915, or the early part of 1916, they present a curious contrast to the National Explosives Factories, the only other national factories of which any representatives existed in pre-Ministry days. The latter, subject to almost every different form and degree of Government control, taken over as often as not from firms which were not working them satisfactorily, established at irregular intervals throughout the course of the war, can hardly be said to have been constructed according to any definite programme.

[1] See below, p. 46.

With the National Shell Factories matters were different. As the needs of the Army outgrew the augmented resources of the armament firms and the Ordnance Factories, energetic measures were taken to open up new sources of supply. By the end of April, 1915, it had been decided that National Shell Factories should be established for the manufacture of the smaller natures of shell, and the local committees which were springing up in important engineering districts were invited to undertake the control of these factories through specially appointed Boards of Management. The Leeds Committee led the way, hoping that the concentration of resources in a single national factory to be operated under one management on a non-profit basis would overcome many of the difficulties in regard to machine tools, supervision and inspection which were being experienced. The scheme for the Leeds Shell Factory was approved on 7 May, 1915.

By the close of June, seventeen factories of the same type were approved, and by the end of the year schemes were ripe for the establishment of some thirty factories under local management boards. The programme was quickly made, the factories quickly determined on. By the summer of 1916, the tale of National Shell Factories was to all intents and purposes complete.

This promptitude was partly due to the obvious urgency of all measures which would increase the existing means of satisfying the Army's constantly growing need for ammunition. Partly, also, the Government was anxious to make use of the free services so generously offered by business men all over the country; it was felt that the management of a factory was a matter on which they could get to work at once, and in which their expert knowledge would be invaluable. Consequently the management of a factory was offered as an alternative, or as an addition, to the scheme for local administration of shell contracts in certain districts.

The National Shell Factory programme thus was swiftly conceived and rapidly carried into effect. The factories fully demonstrated the adequacy of this system for providing the addition to the output of light and medium shells for which they were originally planned. As time went on no necessity arose for the building of more factories for these types of shell; the extension of old ones proved sufficient. And in the greater number of the National Shell Factories the maximum output attained considerably exceeded the original estimates.

Yet it was not to be expected that so many factories, equipped at so great speed, placed under a form of management so new, should be completed without difficulty. Relations with headquarters had to be defined; provisions for the supply of machinery and labour had to be made, trade jealousies and secrecies had to be broken down before the scheme could work smoothly. Sometimes the personnel of the directing Board was wrong; sometimes friction with officials of the Ministry was hard to overcome; sometimes the work was hindered by changes in the orders received.

Nevertheless, it should be remarked that, although there were many cases in which difficulties loomed large at the beginning, and many in which deliveries were belated, there were hardly any which did not

finally attain a large measure of success. In the single instance where an unsuccessful project was eventually abandoned, failure was due rather to the peculiar circumstances of the factory than to the conditions common to the National Shell Factories. The fact that there were no other notable failures must be taken as a proof of success where so many factories were concerned. But at the outset the bulk of these factories failed to fulfil expectations; deliveries began slowly and, with certain conspicuous exceptions, costs were high. The general high costs were especially disappointing in view of the fact that certain of the factories had succeeded in manufacturing at a very low cost, and that the Boards of Management accepted no fee for their work. Delays and the variation in the costs of raw material, etc., paid by the different factories were partly attributable to lack of co-ordination and, in some cases, to the preoccupation of members of the Board of Management with concurrent projects for co-operative manufacture.

Centralised buying and centralised control brought down the costs; even as early as March, 1916, it was found that all types of shell made in the national factories, with the exception of 6 in. H.E., could be produced at a price below contract rates, and six months later all kinds of shell from the national factories were being supplied more cheaply than in the outside market. But the attempt to make exact estimates of the sums saved by the institution of National Shell Factories was abandoned fairly early because of the many conflicting factors that entered into the reckoning. On the one hand, the factories gained by free expert management and supervision and in some cases by obtaining buildings rent free, as at Wrexham. On the other hand, they were frequently handicapped by poor equipment. The Boards often tried to make use of machinery which could be obtained at once and in the neighbourhood, and which was often ill-adapted to the purpose to which it was put. The great haste in which the factories were adapted and equipped sometimes resulted in a bad layout, a permanent disadvantage not to be overcome by any reorganisation.

A considerable strain was placed on the National Shell Factories by constant changes in the nature of the orders presented to them. The factories showed great powers of adaptation. They were designed to produce light shell, and 18-pdr. and 4·5 in. shells were more generally produced than any other type; but when the supply of light shell had for the time overtaken demand, as in the summer of 1916, they turned over to other work and manufactured the larger natures of shell or components for larger natures.

For the most part these factories were situated in the North, where the local committees in large engineering centres nominated Boards of Management. London had only two small National Shell Factories, Ailsa Craig and College Park, and these did not originate in schemes after the Leeds model, but were the works of contractors under the Metropolitan Munitions Committee, which were brought under the Committee's direct control for particular reasons. The only other southern factory, at Bristol, assembled shell components

made locally, but did not manufacture shell. Wales had eight factories, five in the South, in the districts round Cardiff and Newport, three in the North, at Wrexham, Portmadoc and Carnarvon, of which the first had been established by the Liverpool Board of Management and was later handed over to the North Wales Board. In Ireland there were factories at Dublin, County Galway, and Waterford, the last being for the manufacture of cartridge cases. Dublin had three factories, one a fuse factory, at first attached to, but later separated from, the shell factory, at which 18-pdr. shell was the chief product. The third factory was devoted to the manufacture of heavy (9·2 in.) shell, but it remained with the other shell factory under the control of the Dublin Munitions Committee. In Scotland there were two National Shell Factories, Aberdeen and Dundee; of these, that at Aberdeen was among the few shell factories nationalised as late as 1917. It was originally owned by a private firm, but its manager was convicted of malpractices, and the Ministry, while cancelling the contract with the firm, felt it important not to interrupt output and so decided to convert it into a national factory. The Dundee factory was exceptionally well planned and proved particularly agile in turning from one class of work to another.

For the rest, the list of factories is almost a list of northern manufacturing towns, such omissions as there are being for the most part rectified by a list of the National Projectile Factories. The Liverpool Board of Management was responsible for the establishment of an unusually large number of factories: in addition to the four factories in Liverpool (Haymarket, Cunard, Edge Lane and Lambeth Road), it undertook the management of the Bootle factory, sanctioned the plans for the Chester factory, and initiated the factory at Wrexham. Other Boards were for the most part responsible for the management of only one shell factory. Something should, perhaps, be said about the Leeds factories. Of these, there were three shell factories; in point of fact the heavier type of shell was manufactured in them, and until 1918 they were classed as Projectile Factories for purposes of headquarters administration.[1] The Leeds Board of Management, however, having been the pioneers of similar boards throughout the country and having started these factories, retained complete control of them for a considerable time and some measure of control to the end of the war.

The inception of this great group of factories belonged to pre-Ministry days. But the services rendered to it by the first Minister of Munitions should be acknowledged. Mr. Lloyd George, as Chairman of the Munitions of War Committee, gave the principal ministerial impulse to the inception of the scheme before the Ministry of Munitions was created. Later, he did much by his visits to manufacturing centres to encourage the formation of Boards of Management; his authority and initiative expedited production; the conferences held under his chairmanship solved difficulties and evolved practical methods of working.

[1] During the last year of the war the Leeds factories were classed as National Ordnance Factories.

III. The Construction Period, 1915–1916.

The National Shell Factories were established to meet one part of the Army's urgent need for gun ammunition. The vast programme for gun ammunition production launched by the Ministry of Munitions shortly after its creation in June, 1915, was only capable of fulfilment by the establishment of new manufacturing capacity. During the summer of 1915, projects were started for two new classes of national factories. These were the National Projectile Factories and the National Filling Factories. In addition, the number of the National Shell Factories was increased, as has already been seen, while corresponding extensions were made to the existing capacity for State manufacture of explosives. The problem of producing industrial equipment was attacked simultaneously with that of shell manufacture. The first nationalisation of factories for gauges and small tools took place in the autumn of 1915.

(a) National Projectile Factories.

The National Shell Factory programme was designed to meet the need for light shell, but with the adoption of the very large programme for heavy guns and howitzers resulting from the Boulogne Conference (19 June, 1915) the need for heavy shell became equally urgent. Indeed, as time went on there was a growing tendency for the proportion required of heavy to light shell to increase as additional heavy guns came into the field. And with this tendency plant was often turned from the manufacture of light to that of heavy shell, 6 in. being made where 4·5 in. had been made before and so on. But before such adaptations became possible some method had to be found of increasing the supply of heavy shell, since it was clear that even if existing trade facilities were pressed to the utmost the output would fall very far short of what was needed.

Consequently, a month after the Ministry had been formed, a conference was held, under the chairmanship of Sir Percy Girouard, between representatives of the Ministry and of nine armament-firms, whose co-operation was solicited, and by the end of July, 1915, a programme for the establishment of National Projectile Factories had been prepared and accepted. Sir Percy Girouard said at the conference held on 18 July that it was evident :—" That the firms could not increase in any material degree upon their present promises with their present plant," and that "the total of all their anticipations would not come up to anything like the requirements of the Government." It appeared that the quantity of heavy shell required was likely to be four to five times as great as the quantity which could be supplied by existing firms.

The chief difficulties anticipated in the establishment of National Projectile Factories arose from the growing scarcity of machinery and labour and the need for finding competent management for the new factories without impeding the development of existing organisations. These points were to some extent met by the scheme which was finally adopted. Raw material was to be provided, and plant and machinery paid for by the Government, which was also to help

in securing labour. The management was to be in the hands of experienced firms. Working thus with the firms it was hoped that undue competition for machinery and labour would be avoided, and that the fullest possible use would be made of existing organisations.

Some days were spent in the discussion of suitable rates to be paid to the firms for the work they undertook (Messrs. Cammell Laird, Nottingham, refused remuneration of any kind), but on 30 July Mr. Lloyd George approved a draft memorandum confirming the final decisions of the Ministry and the firms. Nine armament firms immediately began the construction of National Projectile Factories; by the middle of November five more were engaged in the same work. That construction should have begun in fourteen factories within five months of the scheme's first being mooted says much for the energy and initiative of those concerned. The only later additions to this group were certain factories the control of which was transferred, in some cases as late as 1918, from contractors or from other sections of the Ministry to the section responsible for National Projectile Factories.

As in the case of the National Shell Factories, deliveries were delayed beyond anticipation; means of co-ordination had to be worked out and methods of central buying developed. With the intensity of the demand for ammunition for heavy guns, impatience for delivery became great. Good methods of supplying labour, raw material and machinery were finally established, and the success of the work done by the National Projectile Factories may be gauged by the fact that the output of all exceeded the original estimates.

The administration of the National Projectile Factories and the relations of the management firms with headquarters were developed in a systematic and successful manner. Careful methods of costing and examination of all orders by the Ministry resulted in prices that were very satisfactory as compared with contract prices. There were no real failures; Birtley was transferred from the management of a private firm to direct management, not because the firm could not work it satisfactorily, but because the Belgian Government had agreed to staff it with Belgian labour and preferred to deal directly with the Ministry of Munitions. This was the only National Projectile Factory in which there was any departure from the system of management inaugurated at first.

The difficulties facing the factories were many; as soon as those arising from the lack of co-ordination had been overcome they were faced with others arising from the lack of forgings, of components and of labour, the shortage of which, as of raw material, became more acute in the last years of the war. Constant changes in orders also had to be dealt with. But after the summer of 1916, when their initial output fell below expectations, these factories fulfilled their functions.

(*b*) NATIONAL FILLING FACTORIES.

At a conference held between the Ministry of Munitions and National and Assisted Projectile Factories, in April, 1916, Mr. Lloyd George, in urging the necessity of speedy deliveries said:—" I am

bringing the same pressure to bear upon the filling factories, but the filling factories sometimes say to me, 'Well, it is no use our forging ahead unless we get plenty of empty shell to fill.' "

A scheme for constructing filling factories had been launched at the same time as that for constructing projectile factories. In this case no conferences with contractors were needed. The filling of shell was not regarded as the monopoly of any group of firms, since practically the whole of the actual shell filling had been carried out in the Royal Laboratory at Woolwich, although a certain amount of component filling was done in some of the large armament and explosives factories. Therefore when it became evident that existing facilities were unequal to the demand a new section of the Ministry was formed in July, 1915, to deal with the problem of gun ammunition filling. On 23 July it was decided at a meeting held under the chairmanship of Mr. Lloyd George that arrangements should be made with firms to build and manage filling factories on behalf of the Government.

It had already been suggested that the neighbourhood of Leeds was suitable for a filling factory, and the Leeds Board of Management had expressed its willingness to undertake the construction and management of the factory, a site being selected at Barnbow. This plan was developed, and the Boards of Management in Liverpool, Glasgow and Gloucester were invited to follow the example of the Leeds Board. These four factories constructed under the supervision of local boards were all designed for the assembling of quick-firing ammunition and for filling breech-loading cartridges with propellants. Construction began at Leeds and Glasgow (Georgetown) in September, 1915, and at Liverpool and Gloucester in October.

Factories of other types were needed. Five, at Chilwell, near Nottingham, Morecambe, near Lancaster, Newburn, near Lemington (Northumberland), at Otley near Leeds, and at Banbury were designed for filling large shells. Six, at Coventry, Perivale, Southwark, Hayes, Abbey Wood and Cardonald, were planned for the filling of fuses, gaines and other minor components. All these factories, with the exception of Newburn, Otley and Banbury, were in process of construction by the end of December, 1915. The construction of Perivale was entrusted to the Metropolitan Munitions Committee; the others were placed under the control of firms acting as agents for the Ministry or of managing directors appointed by the Ministry.

Some delay was experienced in the building of these factories. The selection of the site alone was no easy matter. Proximity to shell producing areas was desirable, yet owing to the dangerous character of the work it was not advisable to have the factories too close to any great centre of population; it was essential to have good railway services, and important that the railway communication with ports of shipment should be direct; finally, the nature of the work required ground especially adapted to a good layout. It was small wonder that several sites were selected and rejected, or that on account of the speed with which new work was carried out some of the sites finally chosen were not entirely suitable and involved the Government in considerable expenditure, in some cases, on the drainage of land, the making of

roads and other similar work. Very considerable difficulty was also experienced in the case of factories for filling larger natures of shells, since neither the nature of the explosive nor the methods of filling to be used were finally settled until the end of January, 1916.

These obstructions did not seriously affect the factories for component filling or for the assembling of Q.F. ammunition. Southwark, indeed, an emergency factory, converted from a large warehouse, was in working order in September, 1915, within three weeks of its commencement. The establishment of the others was not so swift; Southwark, Hayes and Perivale alone had begun regular output by the end of the year; but as for purposes of safety many of the factories were built in self-contained units, it was possible for output to begin from one part of the factory long before the whole was finished. A serious endeavour was made to expedite the completion of the filling factories during the early months of 1916. The projects for Otley and Newburn were then abandoned in favour of more promising schemes, for filling heavy shell, which were undertaken by the managements of the Leeds, Liverpool and Glasgow, Q.F. Filling and Assembling Factories.

As a result of these efforts the National Filling Factories mostly started operations in the spring of 1916. Chilwell, the largest of them, built for the loading of heavy shell, was at work in January, 1916, and had previously worked out methods of filling for general adoption. Output from three others also began in January. Most of the others were working by the end of March.

The 1915 programme supplied the Government with almost all that was needed in the way of National Filling Factories. Few were added to the number later; in June, 1916, the building of a factory at Hereford was begun as an understudy to Chilwell, because the work done by Chilwell was so important that it was thought necessary to have a factory to take its place in the event of its being destroyed. From November, 1916, to April, 1918, the Hereford factory was in operation. It was then closed, but maintained as a stand-by to Chilwell. In July, 1918, the fears which had led to its erection were justified, for a serious explosion occurred at Chilwell, and the Hereford factory was re-opened. Rebuilding began at once at Chilwell and the factory was at work again within a remarkably short time.

An additional fuse-filling factory was established at Luton during the winter of 1916–7. A shell-filling factory at Pembrey, erected by the Explosives Loading Company early in the war, was nationalised at the same time as an adjacent explosives factory from January 1917. In November of the same year the building of two new filling factories began. One, at Gainsborough, was designed to do naval work of a secret nature, filling sinkers with T.N.T., and was controlled directly by the Ministry. The other, at Chittening, was for the filling and assembling of H.S. (or mustard gas) shell, an extremely dangerous process; at first it was intended that the factory should be managed by Nobel's Explosives Company, but the peculiar nature of the work and the labour difficulties which were anticipated led the Ministry to substitute the method of direct for that of agency control. These were

the chief additions to the National Filling Factories after the beginning of 1916. They were mostly erected to meet new needs as they arose.

The main characteristic of the filling factories was the elaborate system of precautions to prevent injury to workers' health through the handling of T.N.T., tetryl and other explosives, and to avoid the dangers of explosion. The filling factories with the explosive factories suffered from these risks. Mention has been made of one of the most serious of the explosions during the war which occurred at Chilwell. An explosion at the Leeds Filling Factory in December, 1916, caused considerable loss of life. A fire at Morecambe in October, 1917, annihilated the buildings, and the Explosives Factory at Ràinham was also destroyed by fire in February, 1918. No other explosions or fires on a large scale in national factories are recorded, and considering the magnitude of the work done it may be said that on the whole the various safety measures taken were successful.

During the year 1916 the National Filling Factories passed successfully through a very difficult period of their existence. The training of an unprecedented number of workers in the careful performance of numerous trifling operations was in itself no easy task. Its difficulty was increased by the novelty of many of the processes and the unfamiliarity of the supervisory staff with this class of work. The quality of the work done improved as the year went on. The most remarkable instance of failure in efficiency was rectified when once the origin of faulty and dangerous ammunition had been traced. During the last two years of the war the filling factories contributed much towards a general raising of the standard of quality in gun ammunition.

(c) Trench Warfare Filling Factories.

The problem of filling trench mortar ammunition was considered at the same time as that of filling gun ammunition, and it was decided that factories should be built at Denaby, Erith and Watford, of which the last should be a national factory. It was, however, found difficult to make suitable financial arrangements for the working of the Denaby and Erith factories. Accordingly they were nationalised in January, 1916, the former being operated under a particularly successful agency agreement and the latter brought under the direct control of the Ministry, as was the case with the Watford factory. Output began from Erith and Watford in October, 1915, and from Denaby in December. All these factories were complete in February, 1916; in the same month a factory at Fulham engaged on similar work was nationalised on the ground of unsatisfactory safety conditions, and the building of a second government factory at Watford was begun. This last factory, Watford No. 2, in addition to filling trench mortar bombs, was used for the assembling and filling of aerial bombs and for assembling chemical shell until this last work was taken over by the Greenford Chemical Shell Assembling Station in January, 1917.

Continual changes were made in the work done by these factories, but with many alterations in demand and numerous developments in the work of the Trench Warfare Supply Department, they showed great adaptability and responded readily to the varying claims upon them.

(*d*) ADDITIONS TO EXPLOSIVES FACTORIES.

The first activities of the Ministry with regard to explosives factories were devoted to the development of schemes already projected, and were diversified by the acquisition of factories already built. The work at Gretna was carried out with great energy under the direct supervision of Mr. Quinan; the original scheme, which had been for an output of 2,000 tons of cordite per month, was enlarged with the idea of producing 3,300. The buildings were scattered over a site of nine square miles, at some distance from any large centre of population, and included new townships for the workers, of whom there were at one time 20,000. The utmost celerity could not produce speedy deliveries from a factory in which every building to accommodate both the plant and the labour had to be created from the beginning. Output from some portions of the plant began in June, 1916, and in the following August all processes were being carried on.

The plans for the factory at Queensferry were also extended, part of the site being devoted to sections for the production of T.N.T. and tetryl in addition to the guncotton section. Arrangements were also made with the Asiatic Petroleum Company for the erection of a factory at Sandycroft, near the T.N.T. section, for the production of M.N.T., and this factory was in 1918 incorporated with Queensferry.

The activities of the Explosives Department were chiefly occupied with the development of the important factories projected or begun before the Ministry was created. Other factories were erected during the first year of its existence, but none on so large a scale as Oldbury, Queensferry, Gretna and Pembrey. The erection of the State picric acid factories did not begin until 1917.

Still, when any deficiency had to be made good, the Ministry decided upon the erection of new State factories. In June, 1915, a factory at Penrhyn Deudraeth, for the manufacture of T.N.T., which was being erected by a private company largely at the expense of the State, was destroyed by an explosion. The company could not undertake the cost of rebuilding, the Ministry felt it imperative to replace the lost capacity and at once took over the site and rebuilt the factory, the first deliveries from which were made in January, 1916. In August, 1915, the building of a State factory for the production of ammonal was begun at Watford; for the most part the Government depended on trade sources for the product, and it was thought well that part at any rate should be manufactured in a national factory. Many different explosives were produced at this factory later. The first deliveries were made in December, 1915.

The erection of a factory at Langwith was begun in November, 1915, so that England should cease to be dependent on Sweden for supplies of ammonium perchlorate. Considerable difficulties were experienced in the working of different sections, and it was not until nearly two years after its inception that there was any output from the factory. By the discovery of simplification in processes smooth working was finally attained and full output was reached in July, 1918. A more speedily successful venture was begun in October, 1915, at Trafford

Park, for the production of pure toluol. The factory was working satisfactorily in July, 1916, and the output far exceeded the original estimates.

Messrs. Brunner, Mond & Company, had, in the spring of 1915, undertaken to erect plant for the manufacture of ammonium nitrate, and under their supervision a group of factories was built near Northwich. The Government had promised to supply them with calcium nitrate from Norway, but the supplies from that country proving inadequate it was decided to resort to home production. Accordingly the Ministry entered into negotiation with the Salt Union Company, Ltd., for the acquisition of the Victoria Salt Works, acquired additional land under the Defence of the Realm Act, and in February, 1916, proceeded to equip H.M. Factory, Victoria, as a national factory for the production of calcium nitrate. In August it was able to deliver supplies from this factory to Messrs. Brunner, Mond & Company's ammonium nitrate factories, which were in the immediate neighbourhood.

Ellesmere Port and Craigleith were planned in the spring of 1916. Of these Ellesmere Port was erected for the manufacture of phenol, to be used in the production of picric acid. For the most part the production of phenol was, like that of picric acid, in the hands of private firms. But towards the end of 1915 it was feared that trade capacity for the output of phenol would prove inadequate and the construction of a factory at Ellesmere Port was decided on. It was begun in March, 1916, and completed in February, 1917, scarcity of labour and alterations in design being responsible for some delay.

Craigleith was the last national factory erected for the production of T.N.T. Its capacity was small as compared with Oldbury or Litherland, being only for the production of 50 tons a week. It was, in fact, designed to replace the output from a small neighbouring factory which had been worked by the Lothian Chemical Company with considerable success, but was situated in a dangerously congested area. The company consisted of two chemistry professors from Edinburgh University, and of a works manager with practical experience. The construction of the Craigleith factory was entrusted to them. It was begun in April, 1916, and the first deliveries were made in February, 1917.

By the summer of 1915, experience had shown the impracticability of certain earlier trade projects for explosives manufacture. Accordingly, the Ministry added to the factories which originated as national undertakings certain works where trade ventures had been subsidised by the State but had not met with success. These included a T.N.T. factory at Hackney Wick, purchased from the contractor in July, 1915, West Gorton and Litherland, which were taken over under the Defence of the Realm Act in October, 1915, and March, 1916, respectively, and the Sutton Oak phenol works. These last had been acquired by the United Kingdom Chemical Products Company in February, 1915 and had been subsidised by the Government in April with a view to extensions of plant. Progress was unsatisfactory in this factory, and after a series of agreements the works were taken over

in January, 1916, the Department purchasing the company's shares. The King's Lynn acetone factory was nationalised in March, 1916, for very similar reasons.

Two cases stand by themselves. The Gadbrook factory for T.N.T. purification was designed and erected by Messrs. Brunner, Mond & Company in June, 1915, but was subsequently accounted a Government factory in view of the specially dangerous nature of the operation and in order to secure its exemption from the terms of the Explosives Acts. In the autumn of 1915 it was agreed that Messrs. Nobel's explosives factory at Pembrey should be nationalised as from the beginning of 1917, on account of the complexity of the agreements with the firm and the large proportion of the capital expenditure already borne by the State. The Admiralty in the first instance entered into negotiations with Messrs. Nobel's for the construction of a factory for propellants which should be operated as a trade factory. Matters were delayed owing to the difficulty of making satisfactory financial arrangements and in February, 1915, the Admiralty cancelled its agreements with the firm, substituting the plans for the Royal Naval Cordite Factory. The War Office had already undertaken to subsidise T.N.T. works which Messrs. Nobel's were to erect at Pembrey. In July, 1915, the Admiralty entered into further negotiations for manufacturing cordite at the same place. The schemes expanded considerably after the Ministry of Munitions was created. In October, 1915, the various contracts were amalgamated for the sake of simplicity and the firm undertook to operate the factory as contractors until the end of 1916, and subsequently as agents on behalf of the State. At the same time the Ministry undertook the whole of the expenditure, instead of seven-tenths as previously agreed.

Of twenty-three National Explosives Factories erected or in process of erection by the summer of 1916, eleven were originally built as State and twelve as trade factories, but of the latter Pembrey was the only one which vied in importance with those projected in the first instance by the State. The building of Craigleith marks the end of those belonging to the first programme of explosive supply. Later developments will be described below.[1]

(e) NATIONAL GAUGE AND TOOL FACTORIES (1915–1917).

As early as July, 1915, it was proposed to establish a central gauge factory under headquarters control. The project did not materialise, but the agreements which were subsequently made with certain firms for an extended output of gauges and small tools brought these works under an exceptional degree of control which practically placed them within the category of national factories administered by agents. The first of these was the Birmingham Small Tools Factory, nationalised in September, 1915. It was followed closely by the Croydon Gauge Factory under an agreement of November, 1915, and similar arrangements were made with the Woolwich Gauge Factory in August, 1916. Two more gauge factories, the Wolseley Motor

[1] See below, p. 50.

Company's Works in Pimlico and the Newall Engineering Company's at Walthamstow were nationalised in 1917 and 1918 respectively, and a factory at Kilburn was established as a national undertaking for the employment of enemy skilled labour in May, 1917.

There was no general scheme for establishing new national tool factories for meeting the general shortage of small tools experienced in 1916. One State factory only was established and two existing factories were nationalised. The Gateshead spade-cutter factory was set up in May, 1916, to make a tool of which the supply was specially difficult. A general tool factory at Westminster was nationalised in 1917 with a view to reorganisation and to improvement in output. In September, 1917, the works of the Hoffman Manufacturing Company were purchased by the Ministry in order to overcome the difficulties experienced in providing ball-bearings for the new aircraft programme. The company had already undertaken considerable extensions and were unwilling to bear the risk of any further expansion in view of post-war prospects. They, however, placed the technical ability of their management at the service of the State.

IV. Further Developments to meet the Demands of 1916.

It has been seen that the great factories erected for gun ammunition supply during 1915–1916 sufficed to meet the needs of the Army in this respect. During the year 1916, while these undertakings were starting up, fresh national projects were launched with a view to supplying other classes of munitions. These, and the later factories established by the Ministry, were very miscellaneous in character, some rendering minor services, some providing only a small proportion of the total product used by the Government, but some of considerable importance. Of those which were initiated in 1916 perhaps the most prominent were the Government Cartridge Factories and the Government Rolling Mills.

(*a*) Government Cartridge Factories and Rolling Mills.

In March, 1916, three trading small arms ammunition firms undertook to erect Government factories for the manufacture of cartridges. The King's Norton Metal Company became responsible for one at Blackpole, Worcestershire, the Birmingham Metal & Munitions Company for another at Blackheath, and Messrs. Eley Brothers for a third at Edmonton. Construction began at Blackheath and Blackpole in the spring but was delayed at Edmonton until August. A fourth similar project was undertaken by the Chief Superintendent of Ordnance Factories at Woolwich. A fall in the demand for the products led early in 1917 to the reduction of capacity to one half. In spite of changes in the kind of product required from these factories, that at Blackpole was extremely successful; greater difficulties were experienced at Blackheath, and though the factory attained a respectable output it tended to lag behind expectations. The factory at Edmonton was the least successful, construction began late and was slow, hopes of reaching maximum output were never fulfilled and

while the other factories adapted their product to changes in requirements, the Edmonton factory ceased production of cartridges, and was transferred to aero-engine repair work in March, 1918.

The decision to erect National Rolling Mills followed on that to erect Government Cartridge Factories. The inferior quality of brass supplied by private mills, and the difficulty of securing adequate supplies of cupro-nickel strip convinced the Government that the desired output of small arms ammunition could not be attained without strong measures being taken to improve the supplies of strip.

Southampton was thought to be a suitable site for the Government Rolling Mills on account of transport and labour facilities, and a great scheme was launched in March, 1916. Certain operations began in November, 1916, but owing to the reduction of demand at the beginning of 1917 the factory was never worked to its full capacity. One result of the decreased output was that manufacture was not as economical as had been expected, and in January, 1918, the cost of production was considerably higher than that of any trade firm. Costs were, however, reduced during 1918. The quality of the output was throughout very high.

(*b*) NATIONAL FACTORIES FOR CHEMICAL WARFARE.

In the spring of 1916 the British Government approved of the use of lethal chemicals in artillery shell, and provision had to be made for the dangerous processes of charging the shells with chemical mixtures, and assembling the charged shells with their bursters and (in some natures) with their cartridges. The former operation was mainly undertaken by trade factories where the chemicals were made; the latter was restricted to national factories, where the conditions as to health and safety could be imposed in the same way as in the National Filling Factories.

A contractor's factory at Walthamstow which had been engaged in the filling and assembling of lachrymatory shell and grenades undertook temporarily the work of assembling lethal shell and was nationalised in June, 1916, but the work of assembling was shortly afterwards transferred, first to the Royal Laboratory, Woolwich, and later to Watford (Trench Warfare Filling Factory) No. 1. In August, 1916, the construction of a national chemical shell factory was begun at Greenford and output began in January, 1917; considerable extensions were carried out later.

A different policy was at first pursued when, in the autumn of 1917, plans were made for the establishment of the first mustard-gas factory at Chittening as a trade factory for making and charging the gas and also for assembling the shell. Construction of the factory began in November, 1917, but, mainly in order to facilitate administration and also to make use of plant at Avonmouth, the work of manufacture was transferred to the picric acid section of the latter factory, and the charging and assembling of the shell was carried out at Chittening, which was completed as a State factory, under the direct control of the Gun Ammunition Filling Department.

These factories, Walthamstow, Greenford, and Chittening, were the only ones set aside for this particular work which involved the

handling both of explosives and chemicals, although during the last year of the war a certain small proportion was undertaken in the ordinary filling factories with a view to utilising spare capacity. The manufacture of chemicals by the trade continued, except that Avonmouth was regarded as the main source of supply for mustard-gas and that a chemical factory at Middlewich was nationalised in August, 1918, with a view to improving output. Towards the end of the war some work upon chemicals was also undertaken by certain of the national explosives factories, where suitable plant had been set free through changes in programme.

The first national factory for anti-gas purposes was not established until 1916, as the original policy of the War Office authorities was to rely upon the efforts of the two firms (Messrs. Bell, Hill and Lucas, and Messrs. James Spicer and Sons) who placed their resources at the Government's disposal immediately after the first gas attack in May, 1915. In 1916, however, a State factory for granule production was established by the War Office at Stamford Hill and began production in February, 1917. In August, 1918, after the Ministry had undertaken responsibility for the supply of this apparatus, two new national factories were set up for the manufacture of a new type of respirator at Holloway.

(c) Additional Explosives Factories.

In the summer of 1916 it became evident that if the demand for explosives came up to what was expected, foreign and trade resources would be insufficient to supply the nitrocellulose powder needed as a propellant, while the use of additional quantities of picric acid seemed imminent. Accordingly some new national factories were begun.

Of these, two, Henbury and Irvine, were for the manufacture of nitrocellulose powder, and were intended to render the country independent of uncertain supplies from America. Building operations began at both in January, 1917, but the entry of the United States of America into the war in April, 1917, completely changed the position of affairs with regard to this product. It was far less expensive to make it in the United States of America, because of the large quantity of imports needed for its production in England. Consequently work at the Henbury factory was reduced in April and given up altogether in May, 1917. The factory at Irvine, however, which was constructed and managed by Nobel's Explosives Company, the only firm in the country which had any previous experience in the production of nitrocellulose powder, was proceeded with and made its first deliveries in February, 1918. The work of construction was slow and full output was not reached before the Armistice. No other national factories were built for the manufacture of propulsive explosives.

For the production of ammonium nitrate a factory was constructed at Swindon early in 1917. Up to that time the Government had mainly relied for this product on the factories belonging to Messrs. Brunner, Mond & Company, in the neighbourhood of Northwich, but it was thought these would be insufficient and the new factory was designed on a scale larger than that of either the Lostock or Sandbach works

erected by Messrs. Brunner, Mond. Some output was received from the Swindon factory in September, 1917, and considerable supplies were received from it during the summer of 1918, but it never worked to its full capacity.

It was in the planning of factories for the manufacture of picric acid that the most ambitious part of the Government schemes consisted in the last two years of the war.

Until the summer of 1916 the Ministry had trusted to trade sources for the supply of this explosive for which the demand seemed moribund. But when in 1916 the abandonment of picric acid was once more postponed and the supply of the raw material (phenol) was increased beyond expectation by the success of the synthetic methods introduced, the Government proposed to erect one vast factory capable of absorbing all raw material; the scheme was enlarged by a decision to lay down plant for fuming sulphuric acid in excess of that required for the picric acid. Construction was begun in September, 1916, on a site at Avonmouth commandeered under the Defence of the Realm Act. The scheme was not developed on the original lines; early in 1917 the picric acid programme was again reduced, mainly for financial reasons; the plans for making this explosive were cut down and the factory was never used for the purpose for which it had been intended. Ten units of the plant for fuming sulphuric acid were completed, and one of these began work in January, 1918, but demand diminished and the plant was closed down after working for seven months. Use was made in the summer of 1918 of the site and part of the picric acid plant for the production of mustard gas, to be used in the filling factory at Chittening. The practical difficulties of starting a new manufacture of this class were enormous. At one time the factory had to be closed because the vessels and baths were impregnated with sulphur, at another because almost all the technical staff were incapacitated owing partly to climatic conditions, which added to the difficulty of ventilation, and finally when mustard-gas was first produced it was so variable in quality that the Chittening factory found it anything but easy to handle. Labour casualties were numerous, reaching as high a proportion as 70 per cent. of the total workers employed in the manufacture, and this intensified the difficulty of securing labour which had from the first been great.

The Avonmouth factory was controlled directly by the Explosives Supply Department. Its history is a remarkable commentary on the change between the conditions in the spring of 1915, when the first explosives factories were constructed and brought into operation in a few weeks, and in the last two years of the war, when stringency of men, money, and materials hampered every new project. The persistence of the Department procured ultimate success in some part at least of the factory; a worse fate attended the concurrent plan for establishing at Billingham a large plant for utilising atmospheric nitrogen in order to secure some measure of independence of South American sodium nitrate. This scheme, after many vicissitudes and after constant examination by a series of financial committees, each one of which admitted its urgency and importance, was finally

postponed indefinitely in view of the difficulty of obtaining labour and materials. Its post-war value was generally admitted, and the factory site and plans were accordingly sold under special conditions to a commercial company for future development.

In order to utilise surplus quantities of raw material which had been produced by novel methods, three more factories were designed for the manufacture of picric acid. They were planned on a comparatively modest scale, at Bradley, Lytham and Greetland, and construction began in all these in January, 1917. In the winter of 1917 the demand for picric acid fell off abruptly; the factories were affected by this in different degrees according to the stage they had reached and their success in production. Building operations at Bradley had been delayed for various reasons; consequently it was decided to use this factory mainly for demonstration purposes. Later, arrangements were made for using the factory for a new process which had proved successful in the private works of the manager, Major L. B. Holliday, and the main work of the factory continued to be of an experimental nature until the close of the war.

The Lytham factory, under the management of Mr. Lance Blyth, made deliveries as early as July, 1917; but although full output was reached at a comparatively early date (November), the cost of production was considerably higher and the efficiency rather lower than in the other two factories. It was transferred to the direct control of the Explosives Supply Department in November, 1917. This change, however, did not secure economical working as compared with the remaining factories, and in March, 1918, when the picric acid demand was again reduced, the factory was closed.

The factory at Greetland was a conspicuous success, though some difficulty was experienced at first in laying the foundations. Production began in September, 1917, and the factory was so well designed and equipped that nitric acid was produced at £1 a ton less than at any other national factory; the costs of picric were continually reduced and the cost of raw materials for each ton produced was £28 less than at Lytham. As a result, when the production of picric was diminished early in 1918, Greetland was encouraged to continue, having proved itself one of the most economical sources of supply. The management was in the hands of Messrs. Sharp and Mallett, acting as agents for the Ministry.

No generalisations can be made about explosives and propellants factories; they were too various in type and too experimental in nature. All that can be said is that the need for explosives was met as it arose, and that it could not have been met without the institution of national factories.

(*d*) Sawmills and Box Factories.

The immense expansion in munitions production during 1916 put an unprecedented strain upon existing facilities for the production of boxes and particularly of cartridge boxes. During the year three national factories were established at Dagenham, Beddington and Woolwich for the manufacture or repair of wooden boxes, and a fourth, at Deptford, for tin box manufacture and repair. The establishment

of national factories was the effect of a definite policy, since it was expected thereby to overcome the difficulty experienced in placing contracts for a store which frequently changed in design and for which there were often emergency demands. Sawmills were also taken over from the original owners, who continued to operate the mills as Government agents. Five only of these were at work in the summer of 1917, but in October and November of that year numerous others were added, as a result of extensive felling operations instituted by the Board of Trade. By that date there were ten box factories in operation, an important part of their work being the remaking of boxes returned from overseas.

V. New Factories of the Period 1917–1918.

The national factories established during the years 1917 and 1918 were of extremely diverse character. State manufacture of explosive materials, such as cotton waste, was undertaken with a view to securing very close technical control over the quality of the product. The general shortage of materials led to the conversion of some of the earlier factories from shell production to ordnance repair, to the establishment of special factories for building materials and to a large expansion in the Government depots for salvage and repair. Manufacture of different novel stores was effected in national factories. An enormous expansion in the aeronautical programme was accompanied not only by the erection of new large scale factories for aircraft and aero-engine manufacture, but also by subsidiary national undertakings such as the Chelmsford ball-bearing factory, already mentioned above, and a machine-gun factory which was sanctioned in October, 1917, for the arming of aeroplanes and tanks, but did not begin production until after the Armistice.

(*a*) Cotton Waste Mills and Wood Distillation Factories.

The bulk of the cotton waste mills existing in this country at the beginning of the war were the property of the British and Foreign Supply Association, and in September, 1915, the Government subsidised the Association so that output should be maintained and the requirements of the national factories satisfied. In August, 1917, the Ministry bought out the Association and became the owner of the mills, retaining the directors as managers. Later it was thought well to establish a still closer technical control over the factories, and the directors resigned in May, 1918. From that time each of the mills was treated as a Government factory and directly controlled by the Propellants Supply Branch of the Ministry. The reorganisation of the mills which followed on their nationalisation resulted in great improvements of method and in more economical working.

In the autumn of 1917, three wood distillation factories were planned to provide the solvents needed in manufacturing aeroplane dope and to utilise waste wood from the large felling operations then begun. Construction of the first two of these factories, Mid-Lavant and Ludlow, began in the spring of 1918, but they had not reached the production stage before the Armistice, while at the third factory constructional work had hardly begun.

(*b*) National Ordnance Factories.

The enormous extensions made to the capacity for gun ammunition manufacture, mainly by the establishment of the national factories planned in 1915, resulted in a large increase in the ration of ammunition per gun. The life of the individual gun was thereby decreased, and by the spring of 1917 guns in the field were wearing out faster than they could be replaced. The obvious remedy was to turn over certain of the shell factories to gun repair or manufacture, and such a change could be more readily made in national factories than by the trade. Accordingly two National Projectile Factories at Sheffield (Messrs. Hadfield's), and Nottingham (Messrs. Cammell, Laird's) and a National Shell Factory (Leeds) began relining guns during 1917, and afterwards undertook gun manufacture. There was also classed among the National Ordnance Factories an entirely new establishment, which was set up at New Basford in December, 1917, for the manufacture of a new type of automatic gun, the 1½-pdr.

(*c*) Salvage Depots and Ferro-Concrete Factories.

The repair and re-manufacture of salvaged material was, to a large extent, undertaken by contractors, but the work of sorting the material took place at salvage depôts, of which five were established late in 1917, under the direct control of the salvage department of the Ministry. The National Box Factories, which have already been mentioned, undertook certain mechanical repairs. The breaking down of rejected ammunition was peculiarly dangerous work and was partly undertaken in the National Filling Factories, where capacity was freed by the reduction in gun ammunition production from the autumn of 1917 onwards. In the spring of 1918 the repair of gun carriages returned from overseas was effected, under the direct control of the Ministry, in an establishment at Southampton taken over from the inspection authority. As early as May, 1916, a national factory for the rectification and repair of fuses was established in the Gray's Inn Road, mainly on account of the difficulty of fixing contract terms for this class of work.

The need for economising all kinds of material was also met by entering upon various Government ventures for supplying materials for building and other purposes. A billet breaking factory had been established at Trafford Park, near Manchester, at the end of 1916, to deal with steel billets from America. It was directly controlled by the Ministry. It possessed the largest billet-breaking plant in the country and so was able to deal with half the imports of steel billets, the other half being distributed among different firms. At Merthyr Tydfil, rolling mills were established at Government expense in connection with blast furnaces, which were also taken over.

Early in 1918 two national factories were founded at Gotham, in Nottinghamshire, and at Yate, near Bristol, for the production of concrete and plaster slab. Both were erected and managed by firms acting as agents for the Ministry.

(d) Factories for Novel Stores.

During the last two years of the war it became necessary to provide a means of making entirely new stores of which bulk manufacture had not before been attempted. In several instances a national factory was chosen for the purpose in preference to the placing of contracts, whose terms would have been extremely difficult to settle, while it was also considered that entire secrecy and immediate production would be easier to obtain in a Government factory. Thus the construction of a special national factory for the R.T.S. incendiary bullet was begun at Coundon in July, 1917, the management being deputed to Mr. J. F. Buckingham, who had invented another type of incendiary bullet, which had been named after him. The two Birmingham Rifle Factories were of a similar nature. Owing to the peculiar skill and experience required for rifle manufacture, no attempt was made to supplement the Royal Small Arms Factory by establishing new Government factories for this purpose. The only exception to this rule was made in the case of the newly adopted Farquhar-Hill automatic rifle, as demand was received for large numbers of this weapon in May, 1918, and it was considered that the only practicable method of supplying large numbers of so novel and complex a weapon was to arrange for a peddled scheme of components manufacture and to centralise assembly in national workshops. Before the factories had come into operation, the demand for this rifle was, however, withdrawn.

A more successful scheme for using a central assembling shop under national control had already been in operation since August, 1917, in Oxford. The Cowley works there had been equipped in the previous March for assembling parts of naval mine-sinkers, which were made under a comprehensive peddled scheme. The essence of this arrangement was a very close control over the receipt and assembling of the components in the national factory, which was managed by an agent in close touch with headquarters.

Although the manufacture of optical instruments in England was strictly limited before the war, no national factory was established in the early days of the war, considerable extensions of plant being undertaken by private firms. A great increase of demand at the end of 1917 led to an appeal from the Periscopic Prism Company to the Ministry to provide funds for new buildings at Kentish Town. It was decided in February, 1918, to take over the original factory, add the new buildings and combine them in a national factory. Three directors were appointed to manage the works for the Ministry.

Soon afterwards another Government factory for the production of photographic lenses was established at Brimsdown, near Enfield. Until early in 1918 the French had supplied lenses for the Hythe Camera Gun, but that year this resource failed, private firms in England could not meet the need, and consequently the Brimsdown factory was built. It made deliveries in July, 1918, and continued them until the Armistice.

(*e*) National Aircraft Factories.

With the exception of the very small, and chiefly experimental output of Farnborough, the Government had trusted to private firms for the adequate supply of aircraft until August, 1917, but the continually increasing demand forced the Ministry, which had become responsible for aircraft production, to recognise the necessity for national factories on a large scale instead of distributing work among numerous comparatively small contractors. It was thus intended to concentrate tuition work, which was extremely heavy in the case of aircraft production, and to obtain the advantages of large scale production already experienced in the great gun ammunition factories. Three National Aircraft Factories were designed at the outset, at Croydon, Liverpool and Manchester, the management of which was to be in the hands of experienced firms. Construction was slow in the case of all these factories. Manufacture at the Waddon Factory at Croydon began in March, 1918, and at the Heaton Chapel Factory at Manchester in April, and the first finished machine was not despatched from the Aintree Factory at Liverpool until June. In no case did the output come up to the estimates, but it must be remembered that the venture was new and launched at a time when labour difficulties were at their height, all the skilled labour in the country being already absorbed in other work.

No concurrent scheme was made to erect new national factories for aero-engine production, one of the main reasons for nationalising aircraft production being the large amount of space required. The output of engines was, however, of very grave moment at the time, and in order to ensure deliveries certain shops were nationalised. A subsidised factory at Hayes was taken over in October, 1917. The automobile works of Messrs Clement Talbot, Ltd., at Ladbroke Grove, were acquired in January, 1918, as a special provision for the repair of Rolls-Royce aero-engines, and the works of the Motor Radiator Manufacturing Company at Greet and Sudbury were nationalised at the same time. Late in the year assembling stations for American machines at Oldham were taken over with a view to general reorganisation.

Other projects for National Aircraft Factories were ultimately abandoned; but a National Balloon Factory was established in the works of a cinema firm at Finchley in January, 1918, to meet a largely increased demand.

The list of national factories established during the war is a long one, but long as it is, its most important items belong to the first two years of the war. In those years were founded the most successful of the great factories for producing explosives, to them belong the programmes of the National Shell, the National Projectile and the National Filling Factories. Minor schemes were carried out with success after the summer of 1916, but all that was swift and dramatic was not only conceived but carried through before that time.

CHAPTER III.

CONSTRUCTION AND EQUIPMENT OF THE NEW FACTORIES.

The problems presented by the construction of national factories were many and great. The buildings were needed swiftly and in large numbers; they were under several different types of management; they produced an immense variety of goods; in some the work done was largely experimental; in explosives and filling factories safety conditions had to be considered; where labour was scarce it was sometimes necessary to design townships as well as workshops. Problems of equipment also were complicated. New buildings, derelict buildings, buildings formerly used for other work had to be provided, and the national factories had no monopoly in the manufacture of munitions. Their construction and equipment was carried on simultaneously with the construction and equipment of factories in private hands, and for awhile there were serious competitive difficulties as to the allocation of labour and material.

It was no easy matter for a newly-formed Ministry to establish authoritative control over the building of national factories: the business concerns to whom this task was, for the most part, entrusted were unaccustomed to official checks and investigations, and the Ministry did not wish to curb their energies, for in the second year of the war output was far more important than economy. Further, for much of the work done there was no precedent, and as a result estimates could not be given beforehand. As time went on, supervision became closer, and finally elaborate methods for checking costs were devised; but as, with the exception of some explosives factories and the aircraft factories, schemes for the more important national factories belonged to the first two years of the war, the new methods could not in many instances be applied to initial expenditure, although they were of great value in the case of extensions, many of which were on a large scale, some involving an expenditure three or four times as great as the original estimates. For example, the first estimates for the Chilwell Filling Factory were £632,100, and the actual expenditure by March, 1918, had been £2,712,097. This increase was mainly due to continual extensions of capacity. Again, the estimate given in February, 1916, of the cost of the Georgetown Filling Factory was £264,100, but the ultimate capacity was four times as great as had been contemplated in the first instance and the cost rose to £1,368,356 by the spring of 1918. At Gretna one extension after another was made, and the first rough estimate of £2,000,000 given to the Treasury in November, 1915, showed little relation to the final cost of over £9,000,000.

I. Construction and Construction Contracts.

(a) Control of Construction.

Speed in construction and in making deliveries was the first thing asked for from the national factories. The great national factory programmes were designed to meet urgent and imperious needs. Construction, not control, was the foremost idea. The Government was prepared to entrust construction to any person, or body of persons, who seemed likely to carry it through efficiently. The main difficulty was to find them. Supervision of construction was not at first entrusted to any single body, but was left to the department responsible for the particular supplies required.

H.M. Office of Works was the outside body to which the Ministry had recourse, when national factories were first being built, for technical advice and supervision. It was called in before the passage of the Defence of the Realm (Acquisition of Land) Act, December, 1916, to assist in acquiring for the Government land needed for factory sites, but not permanently required for military purposes. Also in the summer of 1915 its services were called upon with regard to the construction and equipment of factories. Its functions with regard to the National Projectile Factories were, in August, 1915, summarised as follows :—

(1) Giving a general technical criticism of the schemes.
(2) Making a full investigation of the prices for the erection of the buildings.
(3) Arranging for contracts for the execution of the work.
(4) Placing Clerks of Works on the sites and generally supervising.

The Office of Works was further called in to assist in the construction of the Filling Factories. Mr. (later Sir Frank) Baines, the principal architect of the Office of Works, was specially deputed to assist the Ministry of Munitions, and technical officers were also provided, whose functions with regard to the National Filling Factories were outlined as follows :—

(1) To keep in close touch with the Board of Management.
(2) To expedite the work in every way they could.
(3) To act as Clerks of Works.
(4) To be the technical intermediaries between the Board of Management, the architect, the local contracting firms and the local authorities.
(5) To advise the Board of Management as required on any matter connected with the execution of the work, so as to prevent unbusinesslike arrangements being made, and generally to aim at getting the Board of Management to work on Government lines in a businesslike way, and to prevent the acceptance of prohibitive tenders or offers.
(6) To measure up the work and check the value of the work done.
(7) To certify advances to the contracting firms and to authorise all variations, omissions, additions, etc., as the work proceeded.

To Mr. Baines was entrusted the control of any technical officers sent to the various sites by the Office of Works.

A short time afterwards two appointments were made, one of which strengthened the Ministry's financial control over the construction of national factories, while the other transferred to it some of the functions recently undertaken by the Office of Works. The first appointment was that of Mr. (later Sir Hardman) Lever as Assistant Financial Secretary, in October, 1915, with specific responsibility for all important contracts involving an expenditure of £40,000 and upwards. The second appointment was that of Mr. (later Sir John) Hunter, who was made Director of Factory Construction in November, 1915. His services were secured especially with a view to the supervision of Projectile Factory construction and to hastening their erection in every possible way, but his work and that of the Factory Construction Department was considerably extended later. As far as the Projectile Factories were concerned, Mr. Hunter's appointment left little of its original functions to H.M. Office of Works, except the provision of office supplies.

The position was different with the National Filling Factories. The Office of Works was asked and consented to allow its technical assistants to continue their work on the Filling Factories, and Mr. Baines completed the work he was doing in co-operation with the officials of the Ministry concerned. The Office of Works also supplied auditors for the accounts of the Filling Factories. In some cases it was asked to undertake even more detailed work in those factories, for the National Chemical Shell Assembling Factory at Greenford, completed in February, 1917, was constructed by the Office of Works, and the last National Filling Factory, at Gainsborough, built in the winter of 1917, was also built by it.

The control of construction was slight during the first eighteen months of the war. The single policy which actuated the Ministry was that of securing output by the speediest means. The Treasury had given great financial freedom to the Ministry, and the Ministry gave similar freedom to many of the bodies concerned with factory construction. Building was well under way in many of the Filling Factories before Mr. Baines' services were called upon; ill-defined and varying methods of financial control had been instituted before Mr. Lever became Assistant Financial Secretary. It was no easy matter to impose good methods on chaotic ones, and the finance of construction was not considered satisfactory as late as October, 1917, when the Select Committee on National Expenditure complained that control over money spent on construction was not sufficiently definite.

An attempt was made by Dr. Addison, after he became Minister, to centralize the control of constructional work by the establishment of the Munitions Works Board. This Board, instituted in January, 1917, was a branch of the Finance Department. It was recognised that the various groups of factories had different needs and that no single department would find it easy to deal adequately with the technical side of all the proposed extensions; consequently, in spite

of many discussions as to the possibility of co-ordinating all construction work under one department, it was throughout largely left to the supply departments of the different sections. But the supply departments were instructed to submit all their demands to the Munitions Works Board, and it was the duty of the Board rigorously to examine such demands. Further, the Board was expected to supervise all constructional work.

It was difficult for the Munitions Works Board to assert their control over the supply departments, which had acquired a large measure of independence. The Contracts Department had been responsible for conducting all negotiations with contractors in conjunction, where necessary, with the supply departments, but it was found that in some cases the supply departments had acted without reference to the Contracts Department. In the spring of 1918 the Munitions Works Board was reconstructed with more clearly defined powers with regard to constructional works, including the consideration and approval or rejection of all proposals for capital expenditure and control of the method and cost of execution of the work. Little time remained before the end of the war to test the value of these developments, and the amount of constructional work done during the last six months was not great.

(*b*) Construction Contracts.

There were many differences in the procedure for placing building contracts, not only between factories producing different goods but between factories producing the same goods and between different builders in the same factory. The officials who were responsible for construction in the early days had great freedom and drew up different contracts according to the exigencies of the moment and the demands of those with whom they had to deal.

But the discrepancies in the contracts were not solely due to a lack of coherent policy. Some factories had to be built at great speed, and this caused the use of certain contracts which were later thought unsatisfactory, while the fact that some were built for production on comparatively well-known lines, while others were ventures into unexplored territory, would have necessitated many variations in contract even if central control had been perfect and time indefinite. The following extract from the Comptroller and Auditor-General's Report, 1916–17, illustrates these points in relation to Filling Factories:

> "In the case of all the Filling Factories the estimates put forward in the first instance were made without details of buildings proposed to be erected and without any complete information as to lay-outs. The work of construction was proceeded with in the most rapid manner possible, all considerations being subordinated to speed of construction and attainment of output. The estimates of cost put forward were known to have been made with only the most hazy ideas of what the planning of these factories was to be and with frequent alterations in design owing to changes in filling requirements and mixtures to be used. The construction

work was frequently placed in the hands of managers selected by Mr. Lloyd George and given by him an absolutely free hand to construct or make contracts for construction, *e.g.*, Chilwell to Lord Chetwynd, Hayes to Mr. A. C. Blyth, etc.; they were started at a time when our capacity for filling was ridiculously small and in circumstances which amounted to grave national emergency. The officials concerned with construction would brook no 'interference' or financial control, having in view their charter from the Minister. The estimates of February, 1916, were given when construction had only been a short time started, and the branch entrusted with the work was greatly overburdened with actual supervision of construction."

"There is little doubt that with time for consideration of plans, preparation of estimates and placing of contracts, more economical production might have been secured, but it is probable that the variation in planning has resulted in the long run in the discovery and general adoption of improvements in filling mixtures and methods of filling which could not otherwise have been secured."

The description given was not only true of Filling Factories; it presents the early position with regard to the principal Explosives Factories, and to some extent with regard to Projectile and Shell Factories also, though greater experience could be commanded in planning and building the latter.

The building agreements which gave the greatest freedom to the contractor were time and line contracts, under which the whole cost of construction was borne by the Government, and remuneration was given to the contractor by a percentage payment on the cost of material and labour.

The disadvantages of the system are obvious. Since a percentage was paid on all materials and labour employed, it encouraged rather than discouraged wasteful expenditure. Absence of estimates prevented competition from reducing costs. There was no direct incentive to speeding up labour. It was to the advantage of the contractor to take on more workers rather than to get good work from those he had. Many instances of inefficiency in labour arrangements were quoted in this connection. It was said that "after allowing for the increased rates of wages it had been proved that the productivity of labour at Gretna was something like 40 per cent. of pre-war productivity." In another Explosives Factory at a time when building labour was exceedingly scarce, 50 per cent. of the numerous employees engaged under this system were dismissed without seriously affecting the rate of construction.

Rates of wages were not left to the contractors; they were fixed by the Ministry or Board of Trade arbitrators. But it was in the employment of an unnecessarily large number of workers that time and line contractors often did a grave disservice to the community. The expenditure of an unduly great sum on labour was more mischievous if spread over many than if concentrated on few workers, since it held men back from other work of national importance. Hence determination

of the rates of wages was of little use unless accompanied by close supervision of the number of workers employed and the amount of their output. For this purpose the Finance Department appointed special time-keepers in the various factories. They kept a close watch on the work done, and in consequence discipline was strengthened.

Checks on materials were kept by the appointment of a technical officer of the Department of Explosives Supply to examine all orders, while a Government inspector took account of the material when it reached the factory, and the contractor was instructed to certify the accounts for materials before passing them to the officers of the construction managers.

Much of the construction in the largest Explosives Factories, Oldbury, Gretna, Queensferry, Avonmouth, and in many smaller ones, was carried on under these contracts. They had been common in explosives factories before the war. It was said that :—"the fact that it is impossible to estimate in advance the cost of the work prevents the arrangement of contractors' profit on the basis of a fee instead of a percentage." Mr. Quinan maintained that for work so new no estimates could be given except at a price unnecessarily high, because contractors would not undertake the work unless they were safeguarded by the promise of a reward great enough to provide for all contingencies.

From this point of view it was agreed that time and line contracts were economical. In illustration of this the Projectile Factory at Hackney Marshes may be mentioned. There was some confusion in the original contract for this factory, which was "partly on a lump sum basis, partly on a schedule of rates, and partly on a cost plus percentage basis." Because of the objections to paying in different ways on the same contract it was decided to have the work carried out entirely on a cost and percentage basis, with the result that the final cost was less than it would have been under the lump sum contract.

If for unknown work estimates were insisted on, contractors with no precedent to guide them would ask for sums far beyond the probable cost, lest, the probable cost being exceeded, they should find themselves losing heavily. Mr. Quinan himself absolutely refused to give any estimates of the construction costs at Gretna till the work was well advanced, but in place of estimates he gave an assurance that the cost of the product would not be more than half the price paid for American imports.

Another advantage claimed for time and line contracts was that, where they prevailed, work could be done more swiftly "without the delay which the preparation of complete plans and specifications and the obtaining of tenders would involve." In the construction of large factories the work of designing was so lengthy that the buildings were often complete before detailed plans were ready. To wait for them would have retarded matters to an intolerable extent when production was urgently needed. Further, when, as at Gretna, State manufacture meant a great saving in expense, delay might be as uneconomical as disastrous.

It was generally acknowledged that nothing but great urgency could justify the use of these contracts. They made extravagance profitable to the contractor; and the plan of first making contracts which encouraged wastefulness in material and labour, when both were scarce, and then appointing officials to discourage the wastefulness was, to say the least, unsatisfactory. Yet, for the reasons given earlier, the time and line contract was used to the end of the war in certain factories as being the only one under which firms could be induced to embark on the construction of factories of a new type. As far as possible this type of contract was avoided, not only with regard to any given factory, but in any part of the work in which this peculiar advantage did not apply. For instance, at Gretna time and line contracts were used for the factory and not for the township, since the building of increased hut accommodation for the workers was a matter of repetition work for which the expense could be foretold.

Time and line and cost and percentage contracts were common in the construction of Filling, as in that of Explosives, Factories, and for the same reasons. It is possible that they led to more unnecessary expenditure, for, as has already been indicated, the assertion of financial control over the Filling Factories was peculiarly slow and difficult. Moreover, in the construction of the largest Explosives Factories a department of the Ministry dealt directly with the building contractors. Mr. Quinan, for instance, was himself responsible for the contracts at Gretna and Queensferry. But the largest Filling Factories were controlled by Boards of Management or managing directors, and the terms of the original contracts were not closely supervised by any central department of the Ministry.

There was not generally the same necessity for these contracts in the construction of Projectile Factories, but they were not unknown. The case of Hackney has been mentioned. Time and line contracts were also originally entered into at Birtley, but ultimately the work was taken out of the hands of the contractor and completed under the direct supervision of a representative of the Ministry. The Director of Factory Construction, reporting in January, 1917, to the Assistant Financial Secretary on extensions in Projectile Factories undertaken under cost and percentage contracts, wrote as follows :—

> "Part of the work to be done is the reconstruction and extension of existing work, which involves its being done as and when possible, so as not to interfere with the running of the existing plant. This class of work cannot be carried out on any other basis unless at prohibitive cost."

And again :—

> "The reasons for adopting cost and percentage contracts for all general contractors' work required are, first, the fact that in practically every case the work is largely jobbing work carried out amongst the running plant of the existing steelworks and, second, the fact that there was no time to prepare formal drawings and quantities, even if it had been possible to do so."

He pointed out that similar difficulties were experienced in the case of assisted contracts, *e.g.*, in the case of certain steelworks extensions, and finally summarised the reasons for the adoption of cost and percentage contracts :—

"(1) Cases where the work to be done involved lump sum, schedule of rates and cost and percentage payments and the consequent difficulty in checking materials and labour under these different heads.

"(2) Cases where the managing firms had already entered into such contracts before the Ministry had an organisation dealing with such questions.

"(3) Cases when the preparations of complete plans, specifications and schedule of quantities and the taking of competitive tenders from contractors would have involved such delay in the completion of the works that the value of the scheme would have been seriously affected."

The percentage rates at which these contracts were made fell when both parties to the contract saw what large returns they gave. Hence rates for late were lower than those for early contracts. For instance, the original fees agreed on in February, 1915, at Oldbury, the first great national factory built during the war, were 15 per cent. on wages until 31 August, 1915, and 10 per cent. afterwards, and in addition the responsible firm were to retain all discount on material purchased. These terms were intended mainly to compensate the firm for turning their attention to an entirely new industry, and later contracts were made on similar lines with experienced explosives makers, and in less urgent circumstances, at rates such as 6 per cent. on wages and 1¼ per cent. on materials.

Some of the early contractors also consented to a reduction in the terms of the original contract. This was the case at Birtley, one of the few National Projectile Factories to be built under these contracts. Since there were no estimates of the probable cost of the factories under these contracts the remuneration was, like the total cost, outside the region of prophecy, and so often proved to be altogether beyond it, that, in view of fresh contracts, the firms concerned were willing to revise the terms of the old ones.

The disadvantages of time and line contracts were sometimes mitigated by the purchase of process plant by the Ministry. Both at Gretna and Queensferry it was supplied by the Ministry, and consequently no percentage on its price was paid to the contractors. This affected a considerable saving, since the plant represented about half the total outlay. At Gretna, for example, the total payments to the numerous time and line contractors engaged were estimated in April, 1917, at £3,750,000 ; on this the contractors' commission would amount to about £200,000, or an average of 5·3 per cent. The firms had, in fact, done not much less work than would have fallen upon them had they also had to purchase the process plant ; yet they received only 2·5 per cent. on the total cost of the factory, then estimated at £8,000,000.

The Ministry were throughout fully alive to the advantages of incurring known rather than unknown expenditure. Whenever they could, therefore, without unduly delaying construction, they encouraged the use of lump sum and priced schedule contracts, since under these contracts a definite sum was named as the one at which the work would be completed. Payments were made to the contractor on account, from time to time, on the certificate of architects, engineers or other officials appointed by the Ministry, showing that work exceeding the proposed payment in value had been satisfactorily executed. Final payments were made when final certificates of completion had been received from such officials. The contractors sometimes received a supervision fee in addition to the lump sum, but more often a percentage on it. For instance, most of the management firms which undertook the designing and construction of the Projectile Factories had lump sum contracts with the Ministry, whereby they received in addition to the sum specified—

4 per cent. on the first £250,000.
3 per cent. on the next £250,000.
2 per cent. on the next £250,000.
1 per cent. on any further expenditure.

The priced schedule contract varied from the lump sum contract only in that it entailed the engagement of quantity surveyors to verify contracts and prices.

Lump sum or priced scheduled contracts were made in the first instance for all the Projectile Factories except Birtley and Hackney Marshes, though, as has been seen, other contracts were sometimes used for extensions. Several of the Filling Factories were constructed under them. They were made for a comparatively small number of the Explosives Factories; it is interesting to notice that the three agency factories, Lytham, Bradley and Greetland, designed early in 1917 for the manufacture of picric, were constructed under lump sum contracts, though for Avonmouth, built under the direct supervision of the Department for the same purpose a short time before, a time and line contract had been made.

II. Lay-out and Equipment.

(*a*) Methods of Control.

The early inception of the great explosives factories, the lack of expert knowledge outside the Ministry, the special problems of safety conditions and large scale production, gave the Government a more complete control over their lay-out and equipment than was common elsewhere.

The drawings for the most important of these factories were prepared in a Government office; even those for Oldbury, which was under agency management, were carefully prepared under the direct supervision of Mr. K. B. Quinan. In many of the smaller factories the design was left to contractors, indeed so many of them were begun as private ventures that the Government had no say in the matter until it took them over, when it was often faced by problems of reconstruction and re-equipment.

For the design of the Filling Factories also there was a considerable measure of early central control. The lay-out of the factories for assembling and filling quick-firing ammunition was prepared at headquarters and the work of designing factories for filling large natures of shell, with the exception of Chilwell, for which Lord Chetwynd was solely responsible, was entrusted to the consulting engineer of the Gun Ammunition Filling Department. The designing of factories for filling small natures of shell was, however, left for the most part to the managing director or to the firms acting as agents.

The management firms which undertook the construction of the National Projectile Factories were left to design them according to such methods as their experience suggested, but the designs had to be submitted to the Ministry for approval. The fact that the firms had experience and that considerations of safety were not especially prominent made it unnecessary for the Government to assume so much responsibility.

As for the National Shell Factories, under Boards of Management, the question of equipment was important, but there was no question of design. These works were housed in already existing buildings which had to be adapted to new uses.

The control of equipment was a slow growth, though, as has been seen, the Government in very early days supplied the process plant for Gretna and Queensferry, and the Ministry took a great part of the responsibility for the provision of plant for the Filling Factories. The firms managing National Projectile Factories were at first authorised to buy their own plant. Orders had however, to be submitted to the Ministry, who settled any question of allocation, and before long a more stringent control was imposed, certificates from the Machine Tool Department being required before orders could be confirmed. In the case of National Shell Factories, the Boards of Management were empowered to hire or purchase machinery available in the district. Many difficulties arose later, especially in the National Shell Factories, from faulty or worn equipment, efficiency having been in the first instance sacrificed to speed, and as a result individual factories were unable to yield a large output. This was rectified in the long run by closer control being instituted over equipment, and much of the plant acquired by the Boards of Management was discarded in favour of plant supplied by the Ministry.

(*b*) Old and New Designs.

The erection of the national factories took place at a time when scientific management was coming to the fore and when the cost of labour was sufficiently high to encourage the discovery and use of labour-saving devices. They gave scope for experiments, and the circumstances in which they were constructed greatly increased the importance of methods of economising labour and material. To secure the speediest output possible transit facilities within the factory were of the greatest importance, and it may be noticed here that it was not easy to combine perfect transit with perfect safety arrangements. The method of building in units so that any explosion should affect

a relatively small portion of the works was not readily compatible with methods of passing material from one process to the next. For example, at the largest filling factory at Chilwell the internal transport arrangements were extremely efficient, material and plant passed with the greatest celerity from one part of the works to the next. The factory was built with astonishing speed, and made early, good and economical deliveries. But the factory was not subdivided as were similar ones, into small units. Close connections and complete isolation could not be secured simultaneously, consequently the risks of explosion at Chilwell were particularly great, and another factory was designed to supply the deficiency, should an explosion occur.

In addition to considerations of safety, speed and economy, there were a number of problems arising from the employment of women. Not only was labour scarce, but much of the labour available was that of persons new to the work, and not so strong as that of the men who would ordinarily have been employed. This affected the whole lay-out of factories. The best and newest were designed so that little lifting was needed. Internal rails were constructed, not only to pass as near to the product as possible, so that there was no distance to traverse between the place at which the product was made and that at which it was loaded, but also at such a level that no raising of the product was necessary. These methods would have been advantageous when men were employed ; the employment of women made them essential.

Improvements in design came with experience. Some of the factories built in the first months of the war suffered to the end, both from haste in construction and from defective lay-out, while buildings which were "taken over" were often congested and could only by very careful planning be made fit for the work to which they were put.

Oldbury—the first great National Explosives Factory—was an instance of one which, though carefully designed, was planned without any experience of what could be done on so large a scale. It was built very rapidly because of the urgent need for its products, and before the process to be used had ever been attempted on a manufacturing scale. Other factories surpassed it towards the end of the war in efficiency and in lowness of costs, and this was largely attributed to its early inception and to the swiftness with which it was built.

Greater difficulties were experienced at Litherland, which was begun earlier than Oldbury, in the autumn of 1914, but nationalised later, in the spring of 1916. This factory, which had originally been intended to yield the whole of the necessary supply of T.N.T. for filling small natures of shell, was started in such haste that output was seriously delayed, so ill-balanced was the lay-out, so inadequate the supply of steam, so unsatisfactory the plant. Oldbury was sufficiently well laid out greatly to exceed its estimated capacity, but it was but slowly that Litherland attained its full output, and when it did it had difficulty in maintaining it.

In contrast to these Gretna stands out as an example of a well-designed factory built comparatively slowly for a manufacturing operation which had been in practice for many years. Full time was taken for the construction, so that the best plans might be

developed and the most up-to-date methods of scientific management used. Progress from raw material to finished product for a distance of nine miles was carefully arranged. The factory was divided into areas; in the first stood the glycerine distillery, and the acids, nitro-cellulose and nitro-glycerine sections; in the second the paste sent from the first was made into cordite; in the third were magazines for the finished cordite. The second area, in which the cordite was made, contained units widely dispersed for the sake of safety, and close to it was placed a section for the supply of ether-alcohol to which the solvent recovered from the cordite was sent for distillation. The central electric power station was placed between the first two areas, and the water intake and pumping station was a short distance from the third. Townships, containing not only housing accommodation, but churches, schools, public halls, post offices and shops, were conveniently placed in the neighbourhood of the various sections, so that time should not be wasted by the workers in going to and fro.

Greetland, one of the three factories designed in 1917 for the production of picric, was another example of a well-planned factory. The site was well chosen, lying between the main road from Halifax to Huddersfield on the one side, and the Lancashire and Yorkshire Railway on the other. The order of processes was scientifically managed and the site being below the level of the railway, sulphuric acid could be run by gravity from tank wagons to storage boilers and thence to other parts of the factory. It was chiefly because of the excellence of the lay-out that economy and efficiency were carried to such a high pitch at Greetland; it could, however, not be said that the work was better done there than elsewhere solely because those who planned it learned from the experience of their predecessors, for the contemporary picric factories at Bradley and Lytham were less successful.

As war demands grew, the possibility of expansion became of great importance. Many of the new factories were designed with a view to a possible increase in capacity, many of the old ones suffered from congestion. For instance, Litherland, placed at the disposal of the Government early in the war and converted from the production of aniline to that of first M.N.T. and later T.N.T., suffered from overcrowding. The factory had not been built for the purpose to which it was put, it was not easy to increase the capacity, risk from fire and explosion was great, and the factory was never a very satisfactory one. On the other hand, the Explosives Factory at Ellesmere Port was deliberately planned so that the building should be uniformly capable of housing additional plant. In some other factories the lay-out was designed so that units of production could be multiplied.

The National Shell Factories for the most part suffered from congestion and all the disadvantages of "converted" premises. Certain Shell Factories, however, such as Dundee, proved what could be done when the lay-out was good. The orders received by this factory were peculiarly erratic, but the factory was turned from making one type of shell to another, in some cases, without any stoppage of the day

and night shift. Output maintained a high level, but cost of production was low and the general success of the factory must be attributed to its careful planning.

Difficulties with regard to plant and equipment arose in many of the early factories, and more especially in the Shell Factories, for which the Boards of Management secured whatever plant was available in the area. In some few cases they were fortunate. For the Dundee factory the local Board secured the use of a prize cargo of American engine lathes, intended for Germany. But the local hire or purchase of second-hand machinery led to many difficulties. The Huddersfield Shell Factory, for instance, was ill-equipped and had to be provided with new machinery before it attained any satisfactory output.

In some cases the proper equipment of a factory was hampered by an entire lack of former experience. For instance, the Chittening Filling Factory, designed for charging shell with mustard gas manufactured at Avonmouth, was equipped with an extemporised and unsatisfactory plant, pending the development of knowledge and experience. These conditions increased the number of casualties, particularly among the fitters. Alterations to equipment were made as experience was gained; but the need for immediate output was considered to be so urgent that it was necessary to accept casualties in the factory as the price to be paid for maintaining the equipment and morale of the army in the field.

But for most of the new factories, especially those designed on a large scale, like the great Explosives Factories and the best of the Filling Factories, plant was secured which matched the lay-out. They were splendidly equipped from the first, and those who planned their equipment were never content with it as it stood, but were constantly on the watch for labour-saving devices and constantly making experiments which called for the instalment of new plant which should be more effective than the old.

This was especially the case with the Filling Factories. Chilwell from the first had plant for speeding up processes, and developed the methods which enabled filling directly into the heavy shell instead of filling with amatol blocks to be made universal in the Filling Factories. Block filling increased the difficulties of detonation and also wasted labour, since it involved the use of shells with removable heads or base-adapters. It was accordingly retained in smaller natures only and not applied to the heavy shell, for which a satisfactory means of detonating the block-filled charge had not been found.

In July, 1916, experiments in hot filling were made at Georgetown and proved exceedingly successful. One great advantage of the new process was that it enabled use to be made of existing buildings in filling with 80/20 instead of 40/60 or 50/50 amatol. It was also adopted in October, 1917, for the whole of the American shell-filling programme.

Experimental work in screw-stemming was done first at Morecambe and later at Liverpool, and in the spring of 1917 screw-stemming machines for cold amatol were installed at Chilwell and Liverpool. Experiments in screw-stemming with hot amatol also proved successful, first with a vertical, but later with a horizontal machine, which proved

even more effective. The adoption of these machines represented an enormous saving of labour over the previous methods of hand-stemming. They were restricted to gun ammunition filling, since the filling of trench warfare ammunition was subject to constant changes.

The work of the Filling Factories which were engaged upon components was ultimately highly standardised. The establishment of a standard production unit at Perivale, where experiments were carried out under ideal conditions, did much toward setting a standard to all other filling factories in this respect.

In the shell-making factories standardisation was achieved after a good deal of effort. They were also especially notable for the number of labour-saving devices introduced so that work on heavy material might be brought within the scope of women. The use of overhead cranes, rolling bands, automatic chucks, became common. Crane equipment was the subject of special attention. One instance of this may be given from a National Projectile Factory, in which 6 in. and 9·2 in. shells were handled. It was recognised that light floor travelling cranes were needed in addition to the usual overhead travelling cranes, and consequently a light hammerhead type of crane was designed which fed the machines with single shells lifted from the floor, from benches or from tubs. They travelled the whole length of the bay, supplied with power from electrical feeders laid in underground conduits. Hand jib cranes were also installed for feeding machines used for quick operation on 6 in. shells. These hoisted the shell from a neighbouring bench or trestle arranged at the level of the lathe spindles, the bench or trestle having been filled by the hammerhead floor or overhead cranes. All the cranes—overhead, floor, hand, jib—were managed by girls, with the exception of one heavy overhead crane used for lifting exceptionally great weights.

The cotton waste mills were actually taken over by the Government so that new methods should be introduced. Experimental work was done in them which led to the instalment of improved plant. The Greenfield Mill, for example, was at first used for experimental work, then closed for six months while certain manufacturing trials were carried out by Nobel's Explosives Company. It was then restaffed and newly equipped. As a result there was a very great increase in output. The quality of the product was improved, while the financial effects of the change were highly satisfactory.

Many experiments were made in national factories for simplifying processes and so, by saving the number of stages through which the material went, economising time and labour. Direct filling in the Filling Factories has already been mentioned. Another instance may be cited from the Explosives Factory at Langwith, where in August, 1917, a new process was discovered for certain parts of the manufacture of ammonium perchlorate by which the number of stages was reduced.

The need for economy in labour was evident in very early days; it was followed by an equally great need for economy in materials. The national factories were naturally used as centres for experiments in economy. When the first of the engineering factories were built cost had been disregarded, speed and output being the chief object of

all munition production. Later it was recognised that supplies must not only be adequate for the moment but that they must hold out. The danger of exhausting resources obtained an importance equal to that of the previous need for utilising them to the full. In the case of the first High Explosive Factories, on the other hand, national plant had been erected primarily with a view to economising the basic raw material, since it had been a fixed policy to manufacture as much T.N.T. as could be made for Great Britain and her Allies.

As far as metals were concerned economy was achieved rather by using every scrap of material, than by employing substitutes, though the latter were introduced to some extent to replace aluminium, brass and copper. But both with these and with steel the costing system and the methods devised for following the material from its entry into the factory to its exit, practised first in the national factories and then applied elsewhere, gave the most important results.

Further, since constant changes had to be made in the type of goods manufactured according to the demands of the War Office, the available supplies of steel had to be allocated carefully according to the most pressing needs of the moment. The national shell-making factories were the scene of constant swift readjustment in manufacture; they were continually called on to make first lighter and then heavier shell, and then lighter shell again, and sometimes were turned from shell-making to gun repairing.[1] The existence of factories under Government control which could so immediately be turned from one type of production to another made the task of allocating raw material much easier.

Great economy of material was achieved in the National Box Factories, as in the Shell Factories, by making use of all available material, in whatever form it came. Timber returned by private contractors as unsuitable for their particular work and material obtained from salvaged boxes or brought into the country with foreign supplies were converted into packing cases for munitions. The shortage of wood was a very serious problem: its bulk made it difficult to import when tonnage was scarce, and home supplies were extremely limited.

In the spring of 1917 the Ministry established a centralised organisation for the sale of by-products from the national wood distillation factories, and the initiation of the later wood distillation factories for making use of the waste wood from felling operations carried on by the Timber Supply Department shows how much stress was being laid on economy and how national factories might be used for the purpose. Modern scientific methods were carried very far in all the wood distillation factories, and in the largest of them the value of the by-products more than covered the cost of the acetate of lime, which was the chief product for which they were founded.

Economy both of labour and material was also encouraged by clauses in contracts which gave a bonus on economical working. Such clauses became popular with the Ministry as the need for economy grew, and were introduced as often as possible in the last years of the war. They were, for example, included in the agreements with the firms managing Government Cartridge Factories.

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[1] See above, p. 54.

III. Progress of Construction.

While labour and material for the making of goods grew scarce, material and labour for construction also became scanty. The allocation of constructional steel was carefully considered, and it was always a question whether labour employed in making goods could be diverted to the building of more factories.

As has been seen,[1] though extensions were numerous after the first two years of the war, the number of new factories decreased, and there were many refusals on the part of the Ministry to permit further extensions of existing factories. Shipping accommodation became increasingly scarce, so that it was more and more important to use imports only for the most vital purposes; new demands for steel and iron came with the growing use of aircraft, with the submarine campaign and the development of tank manufacture; builders, not easily replaced by the employment of unskilled and female workers, seemed to become the rarest of all industrial workers. All these things gave pause to new building schemes and concentrated attention on the methods already described whereby the capacity of existing works was increased.

Where new factories were built and extensions made the work of construction tended to be slow towards the end of the war. Countless instances can be given of this. The construction of the Explosives Factory at Ellesmere Port, begun in March, 1916, was retarded by shortage of labour. Later, in June, 1918, when it was decided that alterations should be made in the factory so that it might be used for the production of poison gas, labour was so scarce that it became necessary to employ soldiers, both for construction and process work.

It was, in fact, found necessary towards the end of the war, when construction was needed and needed speedily, to devise new methods of building which should both economise labour and use material which was not in demand. For instance, the Burton Machine Gun Factory was built of thick steel frames, part plates, part boards, with slate roofs. Even so, it was not ready for use until after the Armistice. Buildings could not be erected rapidly except by departing from ordinary methods. They were undertaken only under great necessity, and to the shortage of labour and material must be attributed the fact that several factories and extensions designed some time before the end of the war were not in working order before the need for them was over.

[1] Chapter II.

CHAPTER IV.

FACTORY MANAGEMENT.

When it was decided that national factories should be established, the problem of their management was among the most difficult the Government had to solve. It could only be solved by the use of diverse methods. Some of the factories were built on an unprecedented scale. Many were for the production of goods in the making of which no one had any experience. Engineering firms had knowledge of methods of management applicable to shell production, even if they had none of the actual manufacture of shells. But few firms had any knowledge of high explosives. With some of the new explosives everything was experimental. The Government could not find expert knowledge for the control of these factories, it could only look for managing ability. Hence it was that while the Shell and Projectile Factories were placed as a rule under the management of some expert agency, the control of the Explosives Factories was more often undertaken directly by the Government.

Even where engineering was concerned it was not easy to find enough experts. One method used in 1915 was the formation of the local boards, by means of which engineering experts could pool their knowledge and control great National Shell Factories while carrying on their ordinary business. As the work of the Ministry of Munitions grew, engineers were drawn in ever-increasing numbers to headquarters, where their advice was required on matters of administrative policy. Consequently fewer were left to guide the multiplying activities of factories which were growing rapidly in size and number. Dilution of management became as important as dilution of labour. Heads of engineering firms could only meet the pressure put on them by delegating minor responsibilities and concentrating on great ones. Firms which had hitherto managed one factory managed two or more.

No single method of management could have met the need. The willingness shown by the Government to abandon one method for another was essential to the success of such experimental undertakings. By variety of control and elasticity of method it was possible to discover new managing ability and to make use of all available expert knowledge and of every ounce of patriotic enthusiasm, which led business men to offer their services freely.

I. Types of Agency Management.

As the Government had sought in the first instance to meet the need for munitions by the agency of existing armament firms, so it tried to induce existing firms to undertake the management of the new factories. But the first factories to be acquired or built for the State had to do with the manufacture of high explosives, of which, as has been said, few firms had any experience. As a result, though many

attempts were made to get these factories managed by some outside agency, the Government was often forced into taking them under direct control. Rainham, the first factory to be acquired by the Government, was commandeered for the purification of T.N.T. in November, 1914, under the Defence of the Realm (Consolidation) Act. It was placed under the control of an agency, but this proving unsatisfactory it was transferred to the direct control of the State in May, 1915. Oldbury, the first great national factory to be built for the manufacture of T.N.T., was managed by Messrs. Chance and Hunt, a well-known firm of acid makers. The final contract with this company was settled at the end of April, 1915, though work upon the site had actually begun in January. In this case the method justified itself. The works were erected at an amazing speed, some T.N.T. being manufactured in May and full output being reached in November, 1915. When the Ministry of Munitions took over the work of the Explosives Branch of the War Office, it acquired possession of Oldbury, and Messrs. Chance and Hunt continued to manage the factory for the Ministry on an agency basis.

After the formation of the Ministry, control by means of agencies became common in the Explosives Factories, almost universal in the Projectile Factories, and was resorted to in all the Government Cartridge Factories and in the chief Aircraft Factories. The need for high explosives was so urgent and much of the work so experimental that no definite policy was formulated as to the management of factories for their production. The decision as to whether any new factory should be managed directly or by an agency, was mainly determined by whether a firm could be found competent to deal with it.

Different methods were tried according to the exigencies of the case. Several of these factories, *e.g.*, Litherland, West Gorton and Sutton Oak, were taken over from the firms which were managing them, because of their delay in making deliveries. The decision as to control in the case of the enormous Propellant Factories, such as the guncotton section at Queensferry and the great cordite factory at Gretna, was the result of the system of planning and construction. These were undertaken by the expert staff of the Department, which had been drawn mostly from South Africa. They necessarily supervised the factories during the initial stages of operation and naturally maintained control throughout the war. One or two early attempts to transfer the factories constructed by the Department to operation by agents or contractors had met with failure. Pembrey was the only large cordite factory worked on an agency basis, by Nobel's Explosives Company, and the same firm acted as agents in constructing and operating Irvine for the manufacture of nitro-cellulose powder, in regard to which they had unique facilities.

The Projectile Factories were managed on behalf of the Ministry by big shell firms, with few exceptions. In the case of the shell-making factories the policy was clear. Factories for producing the smaller natures of shell were to be managed by local Boards; Projectile Factories for making the larger natures by private firms. The distinction gave rise to some difficulties, but it was made with the

object of utilising all resources. The National Projectile Factory at Birtley was removed from the management of Messrs. Armstrong, Whitworth early in February, 1916, because of peculiar circumstances. The firm had undertaken in July, 1915, to erect two factories, one for the production of shell, the other for that of cartridge cases. In August, 1915, Belgian labour was introduced, and in the following February a contract was signed between the British and Belgian Governments by which the British Government undertook to pay all expenses, and the Belgian Government to manage the factory and provide labour. The Belgian Government wished to work directly with the British Government. Consequently, Messrs. Armstrong, Whitworth gave up the management of the National Projectile Factory, though they completed the building of it, and continued to operate the neighbouring cartridge case factory on a contract basis. The only other Projectile Factories not worked on the agency basis were the three at Leeds which were under the management of the local Board of Management, and three contractors' factories in the London area, which were taken over as National Projectile Factories in 1918.

The three Government Cartridge Factories were also erected by private firms, with special arrangements for their management. The firms purchased the necessary land and erected and equipped the factories at the expense of the Ministry ; they controlled the factories, but bought their materials from or through the Ministry, which advanced money for their purchase.

Five only of the Filling Factories were managed by private firms. In the case of the Morecambe Filling Factory the management was placed in the hands of Messrs. Vickers, who had been entrusted with that of the National Projectile Factory at Lancaster. The Morecambe Factory was near enough to Lancaster to make it easy and inexpensive to have the empty shell conveyed from the National Projectile Factory for filling purposes. The Coventry Fuse Filling Factory was placed under the charge of Messrs. White and Poppé, who were acting as sub-contractors to a great armament firm and owned an engineering works at Coventry, which was thought to be a good centre for a filling factory. Abbey Wood was managed by the King's Norton Metal Company, which had considerable experience in the type of work to be done. Nobel's Explosives Company was entrusted with the erection and management of a Filling Factory at Cardonald. In January, 1917, the Ministry took over the loading factory at Pembrey, which had been erected and equipped by the Explosives Loading Company, and appointed the company as agents for the administration of the factory as a natural corollary to the nationalisation of the Pembrey T.N.T. Factory. As in the case of the Explosives Factories the Government tried to find firms which because of their experience and the location of their own works were competent to carry out the work. This was an easier matter in the case of component filling and the handling of lesser natures than with the filling of heavy shells. And so many shell-filling factories were needed that private firms could only be found to control a minority of them. The others were controlled directly by the Ministry or by local Boards.

Among the Trench Warfare Filling Factories, Denaby alone was permanently managed by an agency. Attempts were made to control several others by this method, but the negotiations broke down and the Ministry took over the factory management. In the Denaby factory the control of the central organisation was closer than in most factories run on the agency basis, since the Ministry had power to dismiss labour and vary the rates of wages.

In the National Gauge Factories the position was reversed. Except in the case of the Fairfax Gauge Factory, the Government did not establish new works. Consequently instead of the Government's placing its own factories under the partial control of private firms, the firms were placing their factories under the partial or entire control of the Government. There was little similarity in the terms of agreement between the Government and the various firms, but for the most part the firms were more independent of the Ministry than was usual in national factories worked on an agency basis.

In August, 1917, the method of management by agency was adopted for the new National Aircraft Factories. The equipment and management of most of these factories was entrusted to private firms, who carried on the work under the control of the Aircraft Production Department until July, 1918.

Roughly speaking, about one-third of the national factories were run during the early days of the war by private firms on an agency basis. The proportion would have been larger but for the lack of technical knowledge where Explosives and Filling Factories were concerned. The Ministry was reluctant to assume unnecessary responsibility for management, and threw it on to experienced firms whenever they were prepared to undertake it.

II. Management by Local Boards.

(*a*) Constitution of Boards of Management.

Local organisations for the production of munitions had sprung into being even before the inception of the Ministry itself. The initiative and patriotic fervour shown by these local bodies led to various schemes of geographical co-ordination of output and local control. Sir Percy Girouard, after visiting several industrial centres in April, 1915, came to the conclusion that the local committees might be utilised for an important National Shell Factory experiment. He was convinced by that time that new Shell Factories were essential. Early in May, 1915, the general outlines of a scheme for a factory at Leeds to be managed by a local Management Board was approved by the Munitions of War Committee and was subsequently used as a model for all the National Shell Factories. It had great and obvious advantages. It provided expert management combined with an exhaustive knowledge of local resources and provided it freely. The Government, which appointed the members of the actual Boards of Management from the local committees' nominees, did not often appoint more than five members, as the committees spontaneously formed in different areas were too large to conduct executive work with the necessary swiftness.

(b) RELATIONS BETWEEN BOARDS OF MANAGEMENT AND THE MINISTRY OF MUNITIONS.

As has been seen, local committees came to life before the Ministry of Munitions. No strong scheme of central control or of general co-ordination existed when the Leeds Board was asked to take over the management of a National Shell Factory. As a result the participation of the Government in the control was slight. Its sanction was required for action involving questions of compensation, and for new extensions or buildings. It was to be the owner or lessor of all machinery and was to arrange for the ultimate disposal of the machinery, plant and buildings. Auditors were to be appointed by and be responsible to the Government. Equipment was to be carried out subject to the general control of the Government. Apart from these provisions, the arrangement was that the Government should make itself useful to the Board, by bearing the costs, by supplying technical advice, by securing machinery for the use of the Board from recalcitrant owners through the use of the Defence of the Realm Act.

Early agreements made with the Boards of Management were framed on much the same lines, leaving the Boards almost completely autonomous. The position of the Boards was complicated by the fact that as members also of the local committee, they were not concerned solely with national factories but with the working out of important co-operative schemes of production in their respective districts. In some instances these schemes, rather than the efficient management of the factory, were the chief concern of the Boards.

From time to time the powers of the Boards were diminished by the increase of those of the Ministry. The Ministry, bent upon speedy output as well as on the reduction of costs, gradually extended its control. The Superintending Engineers were able to suggest technical improvements which were insisted on by the Ministry. The power of the Ministry was increased by the appointment of the D.A.O. Executive Committee in May, 1916—"to control the administration of the National Shell Factories and of other schemes administered by Boards of Management."

In view of the diversity of the results attained it was thought advisable to create machinery for disbanding the Boards, if necessary. Hence the D.A.O. Executive Committee was empowered to receive reports and call for investigations in the Shell Factories, and to refer to the Ministry any case in which in the interests of efficiency it seemed desirable to disband the Board or change the personnel. In the case of the Metropolitan Munitions Committee the Ministry exercised its power of removing the administrative powers of the Board. This involved the transference to the Ministry of the control of the two national factories, Ailsa Craig and College Park, which were thenceforward administered by the Department responsible for National Projectile Factories.

The powers of the Boards certainly diminished as those of the Ministry grew, but what they lost in power they gained in efficiency, as they were drawn into the great system of which the Ministry was the centre. They acquired knowledge of trade secrets, as the Ministry

insisted that all knowledge about the making of munitions should be used for the utmost increase of production and not for private aggrandisement. They lost the disadvantages of competitive methods and prices as they came more closely into touch with the Ministry and as the Ministry acquired stricter control over raw material and plant which it distributed to agencies likely to make the best use of them. The Boards could not bid against each other for labour or material, while the Ministry was determining the wages of the one and the allocation of the other.

The Leeds "Shell" Factories fell under the management of the local Board. The Leeds factories had, owing to the early beginning and great activities of the Leeds Committee, come under the control of the local Board of Management. In July, 1916, the control of the two factories, Newlay and Hunslet, which were producing heavy shell, was given to the National Projectile Factory Committee, though the powers given to this committee were not to interfere "with the co-operative work of the Board of Management, nor any question affecting the Board as such." In 1917, when one factory at Leeds turned over to gun repair and manufacture, the whole group of engineering factories within the Leeds area was placed under the administration of the Gun Manufacture Department in order to avoid dual control.

It has already been seen that many different methods were employed with regard to the management of Filling Factories. As in the case of the National Shell Factories local Boards were responsible for the erection and control of five of these—Leeds, Liverpool, Perivale, Georgetown and Gloucester. With the exception of Perivale, these factories were originally designed for filling and assembling quick-firing ammunition and for filling B.L. cartridges with propellants. The factory at Perivale was of a different type, and intended for the filling of fuses, gaines and other minor components. The control of the operative side of this factory was transferred to the Ministry in June, 1916, although the Metropolitan Munitions Committee, which had arranged for the erection of the buildings, retained the responsibility for construction and equipment. At Leeds, Liverpool, and Georgetown, the original schemes for filling and assembling quick-firing ammunition were extended, early in 1916, to include factories for filling heavy shell under the same Boards of Management.

It was not easy for the local committees to find men with the technical experience needed for the direction of Filling Factories. They could draw on a large body of engineering experts, but few had any knowledge of the exceptional class of work to be done in Filling Factories. It involved the erection of buildings which should guard against the risk of explosion and of damage done by explosion. Adventurousness was needed, since such factories had never before been built on so large a scale. Caution was essential, since the lives of thousands of workers were at stake. When it is remembered that the services of the members of these Boards were given freely and that the work took up the greater part of their time, it seems remarkable that any were

found to undertake so arduous a task. They constructed their factories speedily and produced large and important outputs. As time went on it was possible for several of the Boards to withdraw from any but an advisory capacity, while the Department's control over technique and finance was strengthened in order to secure the advantages of uniformity during a period of great economic stringency, and to enable the Ministry to fulfil its growing duties in regard to safety conditions. The members of one Board only, that for the Leeds factories, maintained throughout an active and independent interest in the affairs of the filling factories which they managed, and consequently uniformity of method was seriously threatened; but any attempt to strengthen the Ministry's control met with strong local opposition from men who were justly conscious of the great successes of their early efforts to ensure large and speedy production.

III. Direct Control by the Ministry.

It was evident, in quite early days, that the Ministry might in any particular case feel obliged to take over the management of a factory which was not satisfactorily run. Transference to the Ministry was far less invidious than transfer to another agency. Further, it was clear that much of the work to be done was so unlike anything that had formerly been known that it would be easier for the Government to shoulder the whole responsibility itself than to find any agent willing to do so.

There was a tendency, then, for work which had been ill done and for work of a type which had never been done to be undertaken directly by the Ministry. As a result, the proportion of national factories managed in this way increased as time went on. Many of the High Explosives Factories, four of the five Trench Warfare Filling Factories, and several of the Gun Ammunition Filling Factories were managed directly by the Government. But the Ministry to the end avoided direct responsibility for the Shell and Projectile Factories which could be managed on lines with which engineering employers were conversant.

Queensferry was the first and Gretna the second important factory to be managed directly by the Ministry. In the extreme shortage of engineers familiar with the construction of explosives and chemical plant, both factories were planned and erected by the Government's own engineers. Both were started up section by section, and there seems to have been no question from the beginning as to the control of the two factories by the Government.

In March, 1915, the High Explosives Branch of the War Department had secured a derelict engineering works at Queensferry, with a view to adapting it for the supply of explosives for the Army and Navy. The Admiralty, which had long wished to erect a factory whence it could obtain supplies independent of the War Office, brought its schemes to maturity and rejected any share in the Queensferry project at the end of June, 1915. The factory was at once handed over to

the Ministry of Munitions and placed under the factories branch of the Explosives Supply Department. A superintendent was appointed to manage the factory.

Gretna was the result of a scheme for the erection of a great national factory for the manufacture of propellant which was mooted by the Munitions of War Committee in May, 1915. The factory was to make cordite, R.D.B., newly evolved by the Research Department; it was to be on a vast scale so that it might fully meet all requirements; it was to be in an isolated place for purposes of safety. If the Government were ever to control a factory from its inception it was evident that such a factory was suitable for the experiment. Proximity to other factories, so often desirable, was the last thing that was required. Mr. Quinan himself supervised the planning of the factory in the Explosives Supply Department. Messrs. Pearson and Sons, Ltd., were made construction managers and given an extremely free hand in the erection of the factory so as to hasten matters, but the management was from the first in the hands of the officers of the Explosives Supply Department, a superintendent being appointed by the department to carry on the work as at Queensferry.

Of the other Explosives Factories which were taken over in 1915, Rainham was placed at first under an agency management, but direct control was taken in May, 1915, owing to the unsatisfactory progress. With one exception, the management was in the hands of a superintendent under the control of the Ministry in all the other Explosives Factories established as national undertakings during 1915. The exception was the perchlorate factory at Langwith, where the Power Gas Corporation were at first appointed consulting engineers and later a construction manager was put in charge of the works. But the management was brought into line with that of the other Explosives Factories in July, 1917.

The wood-distillation factories transferred by the Office of Woods and Forests to the Ministry were, with the later factories, managed by superintendents under the control of the Propellants Branch of the Ministry. Explosives Factories acquired or built after 1915 and placed under direct State control were managed in the same manner. Of these Litherland, Dundee and King's Lynn were acquired from contractors. When the later programme of the end of 1916, and beginning of 1917 involved the building of several large factories, the Ministry undertook direct responsibility for the erection and management of Avonmouth, but left the control of Lytham, Greetland and Bradley to contractors, since it was easier to get experienced agents for these later picric acid factories than it had been for the earlier T.N.T. factories.

It has already been shown that Filling Factories of a certain type were placed under the control of local Boards, and an equal number under that of certain firms which were thought to have special facilities for managing them. The general policy was to have the factories for the unfamiliar operation of shell filling under direct State control, whilst component filling was left mainly to the trade. In general, a large degree of autonomy was left to the managing directors. They

were frequently entrusted with the construction as well as the management of the factories. For instance, Lord Chetwynd, who was managing director of Chilwell, was entirely responsible for the selection of the site, the design, construction and equipment of the factory as well as for its management. Mr. Blyth, who was managing director both of Hayes and Southwark, also had extensive powers. Central control over the Filling Factories was tightened in time by the Ministry's instituting closer supervision over finance and safety conditions. At first no definite financial supervision was imposed and the lack of such supervision, involving as it did the lack of any consistent policy in the arrangements of the factories, hindered rather than helped their development.

All the Trench Warfare Filling Factories, with the exception of Denaby, were directly controlled by the Ministry. This was not the original intention, which had been to place all of them, except Watford, under the management of private firms. But a change in personnel at headquarters and difficulties experienced in getting the contractors to make any reasonable financial contract forced the Ministry to undertake the management itself.

Certain factories, unique of their kind, were also brought under the direct management of the Ministry. Into this category come the factories built for experimental work, such as the Coundon National Small Arms Ammunition Factory, built in the summer of 1917, and placed under the supervision of a manager appointed by the Ministry. The Southampton Government Rolling Mills was also controlled directly by the Ministry; in this instance the superintendent had considerable powers, being entrusted with the erection and equipment of the factory as well as with its management.

With the elimination of Messrs. Armstrong, the original agents for the National Projectile Factory at Birtley, and the transfer of the National Shell Factories, Ailsa Craig and College Park, to the control of the Ministry in circumstances already described[1] the tale of factories under this form of management is practically complete. It may be said roughly that the need for the simultaneous erection of a large number of Filling Factories and the lack of industrial experience in this work forced the Government to adopt this method deliberately for a large proportion of such factories: that with certain very large schemes for Explosives Factories, it was from the outset considered the best method, as in the case of Gretna, Queensferry, and Avonmouth; but that in other cases attempts were generally made to secure some other means of controlling the national factories, direct control only being resorted to when other methods failed.

IV. Success of Different Methods of Management.

No exact test of the comparative success of the various processes of management can be used. Speed in construction and costs per unit of output would appear to give accurate measurements in time and price. But the number of factories which can be compared on these points is too small to afford any basis of comparison.

[1] See above, pp. 41, .7.

In so far as given types of management were reserved for given types of factory, no definite comparison can be made. The cost of the shell produced under the management of local Boards cannot be set against the cost of the heavier type of shell produced in the Projectile Factories managed by agencies. The length of time it took to erect the Explosives Factories under the direct management of the Ministry cannot be measured against the length of time needed for the construction of the National Aircraft Factories, controlled by agencies. The Filling Factories indeed, furnished instances of all these types of management; but on investigation it appears that the difference in rate of construction arose rather from the nature of the work than from that of the management.

Again, when the Explosives Factories are considered, it would seem as though some exact comparison might be made. There were many such factories, some under agency, and some under direct management. Careful records of costs were made. But when these records are examined it is found that, owing to the large number of different explosives and to the varying size of the plant devoted to their production, no conclusion can be formed as to the efficiency of the various kinds of management. If the records for 1918 are taken with regard to two of the products manufactured most widely, viz., nitric acid and T.N.T., this is abundantly evident. Of eight national factories engaged in the production of nitric acid, four—Oldbury, Greetland, Craigleith and Pembrey—were worked by agencies, and four—Litherland, Queensferry, Penrhyn Deudraeth and Gretna—were managed directly by the Ministry. The four factories with the lowest costs were Greetland and Pembrey, Gretna and Queensferry, *i.e.*, half under one type of management and half under the other. The same consequently was true of the four with the highest cost. The costs at Greetland under agency management were noticeably more than at any other factory, but as this was not the case in other factories managed in the same manner it proves nothing. A similar lack of results is found on examining the costs of T.N.T. Of the six factories producing it half were under agency and half under direct management. Litherland and Queensferry were respectively the dearest and cheapest producers, and both were directly controlled by the Ministry, the difference here being attributable to the comparative advantages of large scale production on a well-planned plant. Pembrey, worked on an agency basis, vied with Queensferry in cheapness, and there was little to choose among the remaining factories as regards cost of production.

It may be suggested that if the elimination of the agents' profits by direct control did not lower the price of its product, the greater efficiency of agency management is proved. But it must be borne in mind that, though the sum total of the agents' profits was great, they were but a small element in the cost of each unit of production, and their elimination could make but a very small difference in the price of each ton of T.N.T. The instances given are too few, the variations in price too wide for any conclusions on this point. With the figures given, profits are an unimportant factor in the sum total of the costs.

So far only negative conclusions have been reached. Nothing has been advanced to prove the superiority of one method of management over another. But by studying more negative facts more positive results may be attained.

First it may be noticed that again and again, when the working of factories on an agency basis was unsuccessful, the management was transferred to the direct supervision of the Ministry with a comparative degree of success. Secondly, that complaints were made as to delay in starting production, both in the National Shell and in the National Projectile Factories. Thirdly, that there appear on the whole to have been more difficulties connected with the working of factories under indirect than with those under direct control.

This does not, of course, prove that direct control would have succeeded at once where agency management failed. But it is in favour of direct control. If, however, the Ministry had assumed direct control of all factories, they would probably have met with far greater difficulties in the quest for efficient managers than they experienced in dealing with experts on local Boards and private firms.

It should be noted finally that although the Ministry successfully transferred several firms from an agency basis to direct control, it also made some unsuccessful ventures when undertaking full control from the beginning. Cases of conspicuous success and conspicuous failure existed under every method of management, and the method of direct control was no more free from failure than other methods were from success. Two of the most efficient Explosive Factories—Greetland and Pembrey—were worked on an agency basis, and these and many others may be set against the unsatisfactory conditions at Lytham and elsewhere. Direct control had great success at Gretna, and in other factories, but it did not achieve it at Litherland. Nor did direct control prevent something of a fiasco at Avonmouth or make the Government Rolling Mills profitable. Yet here again the balance remains somewhat in favour of direct control. For, as has been shown, this form of management was generally introduced either because another had failed or because no other could be secured. Consequently, it may be said that on the whole the method of direct management by the Ministry was employed in factories in which the difficulties were greatest. If, therefore, this form of management has no greater proportion of failure to show than any other, it would seem that its efficiency might be considered greater.

The data are insufficient for more than a tentative judgment. The one thing that remains clear is the great advantage of using different methods and so adapting administration to varying circumstances and conditions. Success in administration is seen to be largely independent of any particular system or method of management.

CHAPTER V.

CONTRIBUTION OF THE STATE FACTORIES.

The national factories were of value in the first instance as a means of increasing supplies, of breaking down monopolies and of lessening dependence on imported goods. These advantages, however, were common to all methods of increasing production, and other advantages may be noticed as peculiar to nationalisation.

In comparing results in old and new factories, and particularly when estimating the achievements of the war time emergency factories, it is necessary to bear in mind the highly specialised character of the latter. They were each one designed *ab initio* for bulk production within a comparatively limited range. They proved highly efficient for their particular work, and achieved results often superior to those obtainable in older establishments. Yet this gratifying result was not secured without sacrificing the balance and elasticity of less specialised productive units, and in fact when submitted to the searching test of post-war utility there were very few that could be utilised as they stood for peace-time purposes.

Large scale production, standardisation, scientific management, improved labour conditions, all the gains of these and kindred methods must leave some mark on industry. The experience gained cannot be lost. Yet the effects may be over-estimated, for to an important extent the war-time experience of the national factories is inapplicable to peace-time conditions. Lessons learned in the Explosives and Filling Factories are not all applicable to industry in general. Moreover, the possibility of large scale production, standardisation, etc., was largely due to the peculiarities of the war demand. Such methods could be carried much further when tons of goods of a given kind were demanded daily. The demands of peace are more varied and call for more elasticity and less mass production. Still, efficient methods having once been practised will, no doubt, spread so far as they are applicable to industries other than those in which they were first used. There can be no doubt that some results are already to be seen in things relating to labour, and to some extent in other matters.

I. Reduction in Costs.

During the war the State became a purchaser on so vast a scale that a true knowledge of the costs of production became a matter of great importance. The buyer of a few goods may pay something for his ignorance of the actual costs, and still more for his ignorance

of means by which those costs could be reduced, but it is not worth his while to become learned in the manufacturing expenses of the various goods he buys. But when manufactured goods are bought by the thousand and by the ton the purchaser may save much if he becomes something of a manufacturer and discovers the cost at which goods can be produced. This is all the more vital when, as during the war, the ordinary marketing is hindered by transport and other difficulties and when, as with munitions, constant changes in orders, involving the use of new methods, are made. There was neither scope nor time for ordinary competition to do its work.

As a result Government factories were of the greatest value both in indicating the lowest costs at which various munitions could be manufactured, and as research centres in which methods of lowering those costs yet further might be discovered.

Not only did the national factories serve these purposes, but they were the basis of an elaborate system of costing, by means of which "bogey" costs could be evolved, giving the costs of raw materials, of labour, and of every process at any given moment and showing the ideal proportion to be attained between the various items of expenditure.

The cost returns furnished by the national factories were partly instituted as a check on undue expenditure. But it was recognised from the first that they would serve the further purpose of diminishing trade prices. Constant references to their success in this matter are to be found in the minutes of committees dealing with finance and economy. For instance, at a conference of National Filling Factory accountants in January, 1917, the chairman, Mr. Webster Jenkinson, mentioned the various purposes to which the cost returns from the National Filling Factories were put by the Ministry and explained how they had already been of considerable use in the reduction of prices charged by private contractors for filling work.

As time went on the costing system became more elaborate. The chief production costs per unit shown in the factory returns were: (*a*) labour; (*b*) materials; (*c*) overhead charges, with the exception of depreciation and interest which were dealt with at headquarters. Rejections and waste of material were taken into account in arriving at the cost. In some factories statistical information as to the production per worker and time per unit was obtained.

The costs of shell produced in the National Projectile Factories compared with the prices paid for contractors' shell show very favourable results, and it was reckoned that at the end of 1917 a total expenditure of £14,659,827 on shell from the national factories had meant a saving of nearly £3,000,000 on what would otherwise have been paid to contractors. It will be seen from the table below that in very few cases was the cost of shell produced in the national factories above the average contract price.

Comparison between Costs in National Projectile Factories and Contractors' Prices, 1917.

National Factory.	Designed Capacity per week.	Cost per Shell. Cost in N.P.F.	Average Contractor's Price.
	I. 15 in., H.E. IV.	s. d.	s. d.
Leeds, Hunslet.. ..	250	772 0	985 0
	II., 12 in., H.E., IV.		
Renfrew	500	441 2	422 0
	III., 9–2 in., H.E, IX., X.		
Leeds, Hunslet ..	2,000	191 0	217 6
Leeds, Newlay ..	2,000	213 9	,,
Sheffield	4,000	153 10	,,
Nottingham	2,000	169 0	,,
Renfrew	—	195 0	,,
Lancaster	3,500	172 8	,,
	IV., 8 in., H.E., III. & V.		
Cathcart	2,000	129 8	156 3
Birtley	4,000	103 1	,,
Cardonald	6,000	92 4	,,
	V. 6 in., H.E., III. IV, VI, IX, XVI.		
Leeds, Armley Road	5,000	64 0	69 3
Birtley	6,000	56 11	,,
Nottingham	6,000	60 6	,,
Lancaster	6,000	82 2	,,
Mile End (Cardonald)	6,000	53 1	,,
Hackney Marshes ..	15,000	74 0	,,
Dudley	6,000	68 10	,,
	VI., 60 Pdr., Shr., II.		
Birtley	4,000	56 3	57 6
Renfrew	10,000	54 8	,,
Lancaster	6,000	49 11	,,
Dudley	17,000	56 2	,,
	VII., 60 Pdr., S.K., & H.E., VI, VII, VIII.		
Cardonald, Moss End	6,000	37 6	51 3
Templeboro'	21,000	47 0	,,

Similar facts can be quoted with regard to the Explosives Factories. T.N.T. was produced in the national factories in 1915-1916 at an average cost of 34 per cent. below the price charged by contractors. The next year the cost was 42 per cent. less than contractors' prices, and this in spite of the fact that the contractors' prices had fallen. In some cases, there were no prices with which costs in the national factories could be compared. In others, where national factories were a late growth, lack of experience in production made the State costs higher than trade prices, and there was no time before

the end of the war to perfect processes. This was the case with the production of picric acid; factories had no sooner been created for the manufacture of this explosive than the demand fell, and only those factories in which state manufacture had been exceptionally successful continued their work. In some few instances the need for economy in materials led to the use of methods in state factories which were more expensive in labour than those employed elsewhere. This happened for a short period in the state production of ammonium nitrate.

It is, however, abundantly clear that although the national factories cost much, they saved much. At Gretna, for instance, it was reckoned that the difference between the cost of propellants purchased in America at the time the factory was begun and the cost of production at the factory was so great that "eight months' full output of the factory taken at this difference is equal to more than the capital cost of the factory." It should be observed in this connection that the cost of building Gretna amounted to over £9,000,000, *i.e.*, more than one-eighth of the total expenditure on all national factories.

Further, part of the cost of munitions produced in the national factories was reckoned as depreciation, and this, together with the saving on contractors' prices wiped out much of the cost of building. To take the most expensive group of factories, those for manufacturing explosives, it was estimated in May, 1918, that the cost of the factories to 31 March, 1918, had been £20,446,539, the saving on contractors' prices £11,368,237, the depreciation included in cost of production, £6,202,479, these last two items making a total of £17,379,574; which when subtracted from the cost of construction leaves only £3,066,995 as the net cost of the factories. This sum would be diminished by output for a greater length of time and might finally be made a minus quantity by the sale of plant and buildings.

The gain was far greater than appeared, and in fact it was less than would have been shown by similar figures given a year earlier, because of

> "reductions in Contract prices, which have been secured partly by reason of the low cost of production at Government factories, which has assisted the Department (of Explosives Supply) in determining what would be a reasonable price to pay to Contractors." Further, "It has to be pointed out that without the Government factories this production could not have been attained in this country, and the erection of factories like Gretna and Queensferry has avoided the necessity of contracting in the United States of America at considerably higher prices than were payable in this country."

Cordite serves as an illustration of both points.

(1.) The average contract price of R.D.B. cordite fell from 2s. 9d. in 1915/16 to 2s. 3¼d. in 1917/18.

(2.) But for the state manufacture of cordite it would have been necessary to purchase the alternative propellant powder

> nitro-cellulose powder from the United States of America at 1 dollar a pound,—though again the competition of Gretna cordite with American nitro-cellulose powder secured a reduction in the price of the latter to 50 cents.

Thus the fact that there was an actual margin of £868,999 between the cost of cordite at the national factories and the average contractors' price is far from representing the true facts and the real gain of state production.

II. Economy in Materials.

If the saving of expense was of great importance to the State, saving of material was vital. Again and again it was admitted that munitions must be secured "at any cost," and factories were carried on even when their costs were higher than general prices warranted because their products were indispensable. But there was always a fear that at no cost could the supplies of certain raw materials be increased, a fear that was converted into a certainty as time went on.

The national factories were of the greatest service in meeting this difficulty. In the first place they facilitated the central control and therefore the profitable distribution of materials. Further, by means of the costing system they were able to show the largest possible output which could be obtained from any given unit of raw material and the extent to which rejections could be reduced.

In very early days managers of national as of other factories bought in the open market. But returns from the national factories showed such great variations in the price paid for goods, and difficulties arose so swiftly from the competition of the Government with private firms for the requisite materials, that state control over supplies was extended from one type of raw material to another. Eventually, most of the important materials for shell making were bought in large quantities by the Government and issued to producers at uniform prices; in some cases the Government purchased nearly the whole of the available supply and the whole supply of platinum, aluminium and antimony was in the hands of the Ministry. Steel forgings were supplied by central purchase; machinery also was centrally purchased under the direction of the Machine Tool Department.

Returns, showing the number of rejections from various factories, did much to reduce the number of such rejections. They were given in great detail in the Filling Factories, and at first there was a very wide discrepancy between the number of shell rejected from the less, as compared with those rejected from the more efficient factories. The circulation of lists giving comparisons of results quickly produced an effect; and was of great service in economising labour and material.

Efficiency costing, which was brought to a very high pitch of perfection with regard to the Explosives Factories, was directly helpful in saving raw material. The second *Report on Costs and Efficiencies*,

for H.M. Factories under the Explosives Supply Department (September, 1918) gave a remarkable record of reductions in the use of raw materials and the circulation of this and earlier accounts was intended to stimulate similar economy of material in all factories.

To give a few instances: at Greetland the amount of phenol employed in the manufacture of each ton of picric acid was reduced from 0·561 tons at the end of 1917 to 0·532 tons in June, 1918. At the same factory during the same period, the $NaNO_3$ usage was reduced from 2·165 tons to 1·961, and of H_2SO_4 from 2·742 tons to 2·014. At Queensferry in the manufacture of each ton of tetryl the HNO_3 usage was reduced from 2·894 tons early in 1917 to 2·328 tons in June, 1918.

In the manufacture of ether the efficiency of the alcohol used per ton of ether made, rose from 96·1 per cent. at Gretna in the first half of 1917 to 98 per cent. in the first half of 1918. The efficiency at Pembrey fell slightly during the same period from 94·8 per cent. to 94·2 per cent.

In the production of each ton of T.N.T. the usage of materials fell, in all the national factories taken together, between the end of 1916 and the beginning of 1918 to the following extent:—Toluene, 0·516 to 0·482 tons; H_2SO_4 usage 0·640 to 0·409 tons; HNO_3 usage 1·239 to 1·005 tons.

Numerous instances of the same nature might be cited, and the prevailing impression received from reading the report is one of continually increasing efficiency in the use of material.

III. Improvements in Processes.

The national factories served as laboratories for the discovery of new and improved methods and for putting into practice experiments suggested by the Research Department at Woolwich. Even in the Projectile Factories managed by experienced armament firms suggestions were made and acted upon which were found to be of value throughout the industry. This was of more common occurrence in the Explosives Factories and in the Filling Factories where much of the work was experimental. Many discoveries were made, many experiments tried which perfected old processes, economised material, and in some cases, revolutionised production.[1]

The State as a large purchaser and a large scale manufacturer found it worth while to introduce and to attempt methods which would have been too risky for any one small firm. Once new processes had been proved by the State small firms could also abandon stereotyped processes, and so the gain became general.

[1] See above, p. 69.

IV. Safety Precautions.

The guarding of munitions factories from sabotage or hostile attack was the concern of a special Military Adviser acting in conjunction with the War Office. Arrangements for the large numbers of police needed for such establishments as Gretna were made by a special Committee on the Policing of Munitions Factories. Fire services and fire prevention in all munition factories, national or trade, were undertaken by a Fire Protection Committee. Under the Explosives Acts, the Government was responsible for safety conditions in all state factories. The experience gained from accidents in these and other works was carefully recorded by a Committee on the Cause of Explosions appointed by the Minister of Munitions in February, 1916, and the regulations put in force were based upon the knowledge so acquired. A great deal of munitions work was of a highly dangerous character, not only because of the risk of explosion but because of the injury to the health of the workers. Where this was the case it was felt that the Government was likely to pay more attention to safety precautions than private firms, and that it was at any rate advisable for national factories to be built which should serve as models to private firms.

V. Output.

Sufficient has been said to show the diversity of method employed in producing various munitions of war. The actual contribution of the State factories to the output of the most important classes of munitions was very large. Statistics for some representative stores are given in the table, which follows. This statement also shows the proportion of the total supplies derived from the State factories, both the old-established Ordnance Factories and the emergency factories which owed their existence to the war. This proportion ranges from 4.7 per cent., the proportion of trench mortars made in the Ordnance Factory during the first two years of the war only, to 78 per cent., the proportion of gun ammunition filling undertaken at the Royal Laboratory and in the National Filling Factories, and 98·6 per cent., the corresponding figure for the filling of trench mortar ammunition.

The comparison of the State factory output with the total home output is even more significant. The proportion of trench mortars from State factories remains unaltered at the bottom of the list, since none of these were imported, and being of simple construction it was the Ministry's policy to obtain them from the small engineering shops of the country. Similarly, the figure for filling trench mortar ammunition remains unchanged, as no filled bombs were purchased from abroad. On the other hand, the proportion of filled shell from State factories to the total home production is raised to 86.4 per cent., since much of the ammunition from other sources was obtained as complete rounds purchased in America.

TABLE SHOWING THE OUTPUT OF THE STATE FACTORIES TOGETHER WITH ITS PROPORTION TO HOME PRODUCTION AND TO THE TOTAL SUPPLY OF CERTAIN STORES.

STORE.	HOME.				ABROAD.	GRAND TOTAL.	Percentage of State Factories Output to Grand Total.
	Total Home.	Contractors	State Factories.	Percentage from State Factories			
Empty Shell.			[O.F., N.P.F., N.S.F.]				
Aug.–Dec., 1914 ..	245,400	168,100	77,300	31·5	—	245,400	31·5
1915 ..	8,314,500	6,904,800	1,409,700	17·0	8,022,400	16,336,900	8·6
1916 ..	33,688,500	25,154,500	8,534,000	25·0	41,848,500	75,537,000	11·3
1917 ..	56,638,800	39,307,800	17,331,000	30·6	27,533,000	84,171,800	20·6
1918 ..	63,820,900	45,461,000	18,359,900	28·8	18,330,000	82,150,900	22·3
Total	162,708,100	116,996,200	45,711,900	28·0	95,733,900	258,442,000	17·7
Filled Shell.			[O.F., N.F.F.]				
Aug.–Dec., 1914 ..	527,800	—	527,800	100	—	527,800	100
1915 ..	5,939,000	859,900	5,079,100	85·5	1,487,300	7,426,300	68·4
1916 ..	45,859,900	8,177,700	37,652,200	82·2	5,736,100	51,596,000	72·9
1917 ..	76,248,700	9,928,700	66,320,000	87·0	11,428,000	87,676,700	75·6
1918 ..	67,439,300	7,644,200	59,795,100	88·7	2,375,200	69,814,500	85·7
Total	196,014,700	26,610,500	169,404,200	86·4	21,026,600	217,041,300	78·0
Rifles.			[O.F.]				
Aug.–Dec., 1914 ..	120,093	68,517	51,567	43·0	—	120,093	43·0
1915 ..	613,461	341,605	271,856	44·3	2,650	616,111	44·0
1916 ..	952,928	534,645	418,283	43·9	406,758	1,359,686	30·8
1917 ..	1,205,672	565,559	640,113	53·0	952,643	2,158,315	29·6
1918 ..	1,062,072	435,742	626,330	59·0	—	1,062,072	59·0
Total	3,954,226	1,946,068	2,008,158	50·8	1,362,051	5,316,277	37·6
S.A.A. (Thousands of rounds)			[O.F., G.C.F., Coundon.]				
Aug.–Dec., 1914 ..			Included in	Figures	for 1915.		
1915 ..	1,194,894	948,127	246,767	20·7	262,062	1,456,956	16·9
1916 ..	2,729,326	2,112,772	616,554	22·6	592,600	3,321,926	18·5
1917 ..	3,136,987	2,337,944	799,043	25·5	97,464	3,234,451	24·7
1918 ..	3,436,602	2,385,300	1,051,302	30·6	—	3,436,602	30·6
Total	10,497,809	7,784,143	2,713,666	25·9	952,126	11,449,935	23·7
Trench Mortars			[O.F.]				
Aug.–Dec., 1914 ..	12	—	12	100	—	12	100
1915 ..	976	480	496	51·0	—	976	51·0
1916 ..	5,554	5,163	391	7·0	—	5,554	7·0
1917 ..	6,194	6,194	—	—	—	6,194	—
1918 ..	6,360	6,360	—	—	—	6,360	—
Total	19,096	18,197	899	4·7	—	19,096	4·7
Trench Mortar Ammunition (Filled).			[O.F., T.W.F.F.]				
Aug.–Dec., 1914 ..	545	—	545	100	—	545	100
1915 ..	411,234	150,140	261,094	63·4	—	411,234	63·4
1916 ..	6,464,989	85,932	6,379,057	98·8	—	6,464,989	98·8
1917 ..	5,051,967	—	5,051,967	100	—	5,051,967	100
1918 ..	4,439,945	—	4,439,945	100	—	4,439,945	100
Total	16,368,680	236,072	16,132,608	98·6	—	16,368,680	98·6
High Explosive.	*Short Tons.*	*Short Tons.*	*Short Tons.*	*Short Tons.*	*Short Tons.*	*Short Tons.*	*Short Tons.*
			[H.M.E.F.]				
Aug.–Dec., 1914 ..	434	434	—	—	—	434	—
1915 ..	16,923	13,248	3,675	21·7	3,283	20,206	18·2
1916 ..	109,578	88,783	20,795	19·0	17,657	127,235	16·3
1917 ..	230,140	156,847	73,293	31·8	29,526	259,666	28·2
1918 ..	203,109	64,621	138,488	65·2	2,047	205,156	67·5
Total	560,187	323,936	236,251	42·2	52,513	612,700	38·6
Propellant.			[O.F., H.M.E.F.]				
Aug.–Dec., 1914 ..	5,298	4,038	1,260	23·8	—	5,298	23·8
1915 ..	12,438	8,784	3,654	29·4	13,535	25,973	14·1
1916 ..	29,617	22,392	7,225	24·4	54,594	84,211	8·6
1917 ..	98,778	49,065	49,713	50·3	106,031	204,809	24·3
1918 ..	77,258	32,644	44,614	57·7	52,938	130,196	34·3
Total	223,389	116,923	106,466	47·7	227,098	450,487	23·6

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CONTROL OF INDUSTRIAL CAPACITY AND EQUIPMENT

PART II

THE NATIONAL FACTORIES

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PREFATORY NOTE.

It is intended that the chapters which follow should record, however inadequately, the achievements of the various national factories during the war. Accounts of the establishment and work of individual factories have been grouped under the main classes into which these factories generally fell for administrative purposes. The groups have been arranged roughly in chronological order, beginning with the Royal Ordnance Factories which were already in existence at the outbreak of war and ending with the National Aircraft Factories which were still in course of erection at the close of hostilities. A chapter[1] has also been added on the other miscellaneous, but numerous, factories which were controlled by the Ministry of Munitions for multifarious purposes. Within this chapter also the various groups have been arranged in approximately chronological order.

Owing to the diversity of the work undertaken by many factories, it has not been practicable to classify them according to the operations which they performed. State manufacture of guns, for instance, was carried out at the Royal Ordnance Factories and at certain Shell and Projectile Factories. In consequence, several important factories belonged to more than one class at different periods of the war. For instance, the factories which were converted to gun manufacture were classed during the latter part of the war as National Ordnance Factories. The introductory statement on each class of factories should form a general guide in this respect.

Considerable difficulty has been experienced in defining the term "national factory." To have limited it to establishments under the direct control of the Ministry would have ruled out very important classes which were administered by agents, as, for instance, the National Projectile Factories. An agency agreement, however, approaches very nearly to the cost plus percentage type of contract, under which the Ministry often bore the capital expenditure and paid the actual cost of operating a factory. Roughly speaking, such agreements have been included when the agent definitely undertook to operate the factory on behalf of the State. The net has been cast somewhat widely to take in establishments where there were special reasons for claiming Government control, such as the Gadbrook Factory, which was accounted a national factory for the purposes of safety conditions only. No attempt, however, has been made to include all works whose names imply state-ownership, such as "H.M. Potash Factory, Oldbury,"[2] or other factories, which were similarly intended as national works, but were eventually operated by contractors, as, for example, the Trafford Park Tractor Assembly Factory.[3]

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[1] Chapter IX.

[2] Vol. XI, Part III, p. 76.

[3] Vol. XII, Part VI, p. 5.

State-owned plant within the works of contractors has also been excluded, even when it was operated by the servants of the Department, as was the case, for instance, with various experimental plants. Neither has any account been given of the numerous establishments which were engaged upon research, even upon a semi-manufacturing scale. A list of these will be given elsewhere.[1] The term "factory" has been taken to include those works which undertook manufacture, and in some cases salvage and repair. It accordingly excludes the large classes of inspection and storage depôts, mines, quarries and other similar undertakings which were controlled by the Ministry. The schedule of factories which is given in Appendix IV shows the main details relating to each of the factories included in this account and denotes the stage reached in the development of state manufacture at any point of time during the war.

The capital expenditure on the factories has been taken from the balance sheets for March, 1918, or March, 1919, whichever figure best showed the actual cost of the factory. The figures relating to labour have been taken throughout from the monthly Reports on Labour in Government Establishments, prepared by the Intelligence and Statistics Section of the Ministry. The introductory statements relating to the more important classes of factories aim only at showing the chief characteristics of the various types. They include some details touching schemes for erecting national factories which did not materialise and touching some minor establishments of which no detailed account appears.

The general circumstances which attended state manufacture on the enormous scale to which it was developed by the Ministry of Munitions have been described in the preceding section of this History.[2] The narratives, which follow, will be found to contain abundant evidences and illustrations for the conclusions there drawn. An account of the policy in regard to the post-war disposal of the national factories is given elsewhere.[3]

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[1] Vol. IX, Part II, Appendix IV.
[2] Vol. VIII, Part I.
[3] Vol. II, Part I, Supplement.

CHAPTER I.

THE ROYAL ORDNANCE FACTORIES AND THE ROYAL AIRCRAFT ESTABLISHMENT.

I.—Introduction.

There existed at the outbreak of war, four state-owned undertakings for the manufacture of munitions. Three of these were old-established factories engaged upon various classes of equipment. They were the Royal Ordnance Factories, which included the group of factories forming the manufacturing establishments at Woolwich Arsenal, together with the Royal Small Arms Factory at Enfield and the Royal Gunpowder Factory at Waltham Abbey. The fourth establishment, the Royal Aircraft Factory at Farnborough, was of comparatively recent date. All four were controlled by the War Department, although the output of the first three was divided between the two Services. Since 1909, the control of the factories at Enfield and Waltham Abbey had rested with a single head, the Superintendent of Waltham and Enfield, but the accounting for all three of the Ordnance Factories had been centralised at Woolwich, where the various manufacturing establishments in the Royal Arsenal were controlled by the Chief Superintendent of Ordnance Factories.

Certain classes of naval work, such as the filling of naval shell, were also carried out on a comparatively small scale at outstations or depôts. The account of these depôts, which were under Admiralty control, does not, however, come within the scope of this statement; while the general development and functions of the Royal Ordnance Factories have already been considered elsewhere.[1]

II.—The Royal Ordnance Factories, Woolwich.

(a) *Administration.*

The administrative organisation of Woolwich as it existed in 1914 had not materially changed since the reorganisation which took place in 1887 as a result of Lord Morley's Committee of Enquiry. The member of the Army Council responsible for the Ordnance Factories was the Master-General of the Ordnance, who controlled them through the Director of Artillery. The control exercised by the Director of Artillery was, however, confined principally to placing orders and giving instructions on technical matters from a military point of view, general control of the factories as a whole being left entirely in the hands

[1] Vol. VIII, Part I.

of the Chief Superintendent of Ordnance Factories. No codified statement existed as to the subjects which had to be referred by the Chief Superintendent to the Director of Artillery, but they were roughly questions as to personnel, pay, building services, machinery and purchase of material, and included all permanent promotions to the rank of foreman and above, special increase of pay, and increases affecting a class of employees. Practically all building services and all schemes for extensions to plant were referred for sanction. In normal times small purchases of material up to the value of £25 (or £100 for building) had been allowed without War Office sanction being required, with an extension to £100 for urgent cases. This limit was extended after the outbreak of war up to £500, monthly reports being rendered to the War Office. For urgent requirements War Office sanction was obtained after the event.

Orders to manufacture were conveyed to the Chief Superintendent of Ordnance Factories by means of the "extract." This document, which is of early origin, was devised to avoid the issue of direct orders by one official to another of equal rank, and consisted of an extract from the proceedings of a Board of Ordnance, which originally met at the Tower. Woolwich received its extracts through the Deputy Director of Ordnance Stores, Woolwich, for the Army, through the Superintendent of Ordnance Stores for the Navy, and through the Inspector of Royal Engineers' Stores for the Director of Fortifications and Works.[1] Allocation of work to the Ordnance Factories and trade firms respectively was settled at an allocation meeting consisting of representatives of the Admiralty and the War Office; but, except for indications as to urgency, priority of work was left to the discretion of the Chief Superintendent. The extract authorised the Chief Superintendent of Ordnance Factories to order raw material and plant, to engage labour and take any other steps necessary to produce the stores required. Raw material and trade supplies of plant were ordered through the Director of Army Contracts. The Deputy Director of Ordnance Stores, Woolwich, was an officer in the Department of the Quartermaster-General working under the Quartermaster's subordinate, the Director of Equipment and Ordnance Stores. He performed his functions as to the requirements of the Master-General of Ordnance under instructions from the Director of Artillery, and for the Quartermaster-General's stores through the Quartermaster-General, this dual authority being a relic of the time when the Quartermaster-General and Master-General of Ordnance were not separate officials at the War Office.

In August, 1914, the Royal Ordnance Factories at Woolwich were divided into departments as follows:—(1) The Royal Laboratory, where ammunition of all kinds was made and filled; (2) The Royal Gun Factory and Royal Carriage Department, dealing with guns, gun carriages, wagons, ammunition boxes and transport of various descriptions; (3) The Mechanical Engineer's Department, which dealt with

[1] Service stores for this department were ordered through the Deputy Director of Ordnance Stores, and experimental and departmental requirements through the Inspector of Royal Engineers' Stores.

the general engineering requirements of the whole Arsenal; and (4) the Building Works Department, which was responsible for all buildings, extensions, road and railway traffic. Each of these departments was administered by a superintendent, and, in addition, the Chief Superintendent had a Military Assistant and a Civil Assistant, the latter dealing with accounts, finance, stores and pay, and the former assisting the Chief Superintendent on technical questions.

The Royal Laboratory, the department of the Ordnance Factories which expanded most during the war, underwent some reorganisation during that period. Prior to the war several officers, subordinate to the Superintendent of the Royal Laboratory and known as the Assistant Superintendent and Danger Building Officers, carried out all work in connection with explosives and the filling of small arms ammunition. In March, 1916, the Royal Laboratory was split up into three main divisions, the Filling Factories, Small Arms Ammunition Factories, under Controllers, and East and West Laboratory, under a Superintendent of the Royal Laboratory. The Small Arms Ammunition Factories dealt with the manufacture of small arms ammunition; the manufacture of empty shells, bombs, primers, fuses, cartridge cases, etc., was carried out in the East and West Laboratory, while all filling was done in the Filling Factories, the Controller of which was also responsible for the tailoring, paper and leather factories.

The Gun Factory and Carriage Department were originally separate, but had been united under one superintendent in 1907 in order to secure greater co-ordination in the work of the two factories. From 1917 until the end of the war the Superintendent of the Gun and Carriage Factories had an Assistant Superintendent in the Gun Factory and in the Carriage Department a Deputy Superintendent, a first assistant in charge of the woodworking department and a second assistant directly under the Deputy Superintendent's orders. All these were military officers, and the Deputy Superintendent, who was a mounting specialist, had considerable latitude in control and in originating design, the Superintendent himself being a specialist in gun design.

When the responsibility for the supply of munitions was taken over in June, 1915, by the Ministry of Munitions, the control of the Royal Ordnance Factories did not at once pass to the Ministry, though it was understood that the whole of the technical resources and the experience of the staff should be made available to aid the development of munition supply. The position of the Factories was the subject of much discussion between the War Office and the Ministry, the principal object being to secure the transfer without dislocation of the work. The transfer was from the first considered to be merely temporary, and a scheme for a partial transfer was put forward, but it was finally recognised by all concerned that a complete transfer of full administrative control could alone be satisfactory, and this was agreed to in principle by both parties in August, 1915.[1] Mr. Lloyd George, then Minister of Munitions, allocated the control to the Director-General of Munitions Supply, whom he proposed to provide with a Consultative Committee

[1] HIST. REC./H/1122.11/1.

on Management. This committee, which was representative of the War Office and Admiralty and the chief supply departments of the Ministry concerned, was to be the medium for considering with the Chief Superintendent of Ordnance Factories and the Superintendent of Waltham and Enfield, matters affecting the placing of large programmes and questions of output. Extracts were to be placed by the Ministry, and a section (C.M. 7) was formed under Mr. Eric Geddes, then Deputy Director-General (C) of the Munitions Supply Department, to deal with extracts and correspondence with the Ordnance Factories relating to such questions as pay, personnel, extensions, supply of machinery, statistical returns as to output and progress and the quality and efficiency of products. The Chief Superintendent, Sir H. F. Donaldson, K.C.B., became technical adviser to the Ministry in September, 1915, and was succeeded at Woolwich by Sir Vincent Raven, K.B.E., who remained in control until June, 1917. Sir Vincent Raven's successor was General C. P. Martel, C.B., who had been Superintendent of the Royal Gun and Carriage Factory.

The Deputy Director of Ordnance Stores still retained the right to place extracts for less than £250, sending copies to the War Office and the Ministry, and the Ministry agreed to this on the assumption that such extracts would be for urgent stores, stipulating only that the Chief Superintendent should first be asked whether he could execute the order. The Admiralty and the Works Department still issued their extracts on Woolwich independently,[1] through the Superintendent of Ordnance Stores and the Inspector of Royal Engineer Stores respectively. The relations between the Ordnance Factories and the Ministry thus became for practical purposes the same as those between the Ministry and any large armament firm, the Chief Superintendent acting as a General Manager, and deciding what orders could be accepted.

Until the Ministry of Munitions took over the control of the Woolwich Factories, the Filling Factories were supplied with components by the Army and Navy Ordnance Departments. This arrangement cut across the policy of the Ministry, whereby it assumed responsibility for all stores until they were finally completed, and in January, 1916, it was arranged that the Chief Superintendent, represented by the Controller of Ammunition Components, should take over all the stores and buildings, all components in stock, the staff in charge of the stores, and some of the office staff, who had previously carried out this part of the duties of the Deputy Director of Ordnance Stores, Woolwich. From that time the Army Ordnance Department was concerned only with the receipt and storage of finished stores. The former arrangement still held good for naval stores, empty shell passing on arrival at the Arsenal into the charge of the Naval Store Officer, and being distributed by him for filling, and again passing into his charge after filling.

[1] Later, to avoid the difficulties incidental to two departments giving orders separately for filling ammunition at the Arsenal, a weekly meeting was held between Admiralty and Gun Ammunition Filling Department representatives when the Woolwich filling programme was arranged (C.R./Filling/384).

Section C.M. 7 was informed of the main items of work going through the Arsenal. The supply officers of the Ministry corresponded direct with the factories on matters concerning the particular store in which they were interested. This arrangement secured a fairly unified headquarters control, though the Consultative Committee was entirely abortive. In November, 1916, however, the work of Section C.M. 7 was discontinued, and all correspondence relating to manufacture, supply, and inspection was carried on direct between the department concerned and the Chief Superintendent, through the Central Registry. With regard to extracts, each department minuted the Chief Superintendent direct, giving the particulars of the extract which they wished to have issued. The extract was then prepared and returned by the Chief Superintendent if the order could be accepted. Sir Charles Ellis was nominated to deal with any matters of importance which might be brought before him by the supply departments or the Chief Superintendent, and he continued to do so until the formation of the Munitions Council,[1] when this responsibility passed to Sir Glynn West as Council Member G.

With the disappearance of Section C.M. 7 all centralised administration of the Ordnance Factories ceased. There was no one organisation within the Ministry to which the Chief Superintendent could look for assistance in general matters, and there was no one at headquarters with complete knowledge of all the productive activities of all the Factories, and able to advise on the nature and amount of work to be done there in the future. The Council Member had no one to whom he could delegate the work of dealing with the mass of detailed correspondence which flowed to and from the Arsenal. When Sir James Stevenson succeeded Sir Glynn West early in 1918 as Council Member responsible for the Ordnance Factories, he pointed out the unsatisfactory nature of this arrangement, and suggested the appointment, within the Ministry, of a Controller of Ordnance Factories,[2] who should be responsible to Sir James Stevenson as Council Member. He thought it was no function of a Council Member to deal with details such as came to headquarters from Woolwich, until they had been sifted and decisions as to policy were required.

By this time the productive capacity of the country for the manufacture of munitions had developed on such a scale that it was possible to give greater weight than had hitherto been found practicable to questions of economic and efficient production. A plan was under consideration for decentralising the manufacturing work of the Ordnance Factories to the new national factories, and the whole question was referred by the Minister of Munitions to a Committee of Enquiry, under the chairmanship of the Right Hon. T. McKinnon Wood, with the following terms of reference :—

> " To enquire into, and report upon the control, administrative organisation, lay-out and equipment of the Royal Ordnance Factories at Woolwich, and the nature and distribution of the

[1] HIST. REC./R/1122.1/1. [2] M.C. 537.

work carried on in them and at the Arsenal generally, and to advise the Minister of Munitions what, if any, changes are required.

"The Committee should have due regard to the importance of efficient and economic production, and the necessity for maintaining a reserve of productive power, and should give weight to the obligations of the Government as an employer to ensure the best possible industrial and housing conditions of the employees."[1]

The Committee made various recommendations as to the control and management of the Arsenal, but as their report was not presented until after the Armistice, it does not enter into the scope of this history.

(b) *The Site of the Factories.*

The suitability of Woolwich as a site for a national arsenal has long been a subject of debate. An ideal Arsenal should not be near the frontier,[2] but in consequence of the convenience of Woolwich for supplying the Navy and the colonies, its advantages for water transport and the political difficulties incident to any change, the discussions have never resulted in any action. A disbelief in the possibility of invasion and a desire for economy may have been contributing factors to this result. After the Crimean War there was a definite intention to remove the whole Arsenal to the Midlands,[3] but this opportunity was allowed to pass and the developments then made at Woolwich rendered any subsequent removal a very costly undertaking.

The question was raised again in 1907 by the Treasury on economic grounds. One of the terms of reference of a committee then presided over by Sir G. Murray was :

"to enquire into the effect which the concentration of Government manufacture and workshops in the Metropolitan Area has on rates of wages and cost of living, economy of production in time of peace, and power of expansion in time of war and to enquire what change, if any, is desirable in the present distribution throughout the country of such manufacture and workshops."

There was some ground for believing that the Government might well follow the example of private enterprise and seek some more favourable area of production nearer the sources of supply of coal and iron, where the burden of local rates was less and the prevailing standard of wages lower. It was evident, however, that a very considerable saving would have to be assured to balance the immense expenditure involved in acquiring a new site and providing new buildings, machinery and housing. The committee decided that to transplant the Arsenal as a whole seemed impracticable, and to transplant a part was useless in view of the interdependence of the different factories. They also felt that any such transfer might defeat its own object, since the sudden concentration of a large industrial

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[1] Hist. Rec./R/1122.11/8.

[2] *Proceedings of Royal Artillery Institution*, Vol. VIII, 110–11.

[3] Hist. Rec./R/1122.11/19.

population on the outskirts of an industrial town would go far to create a similar state of affairs to that from which it was desired to escape, while the selection of a site in a remote area would present housing difficulties and there would be no reserve of labour to draw on in an emergency. The proximity of Woolwich to Shoeburyness was also a strong argument in favour of retaining the Ordnance Factories at Woolwich, since it was very essential to have the factories near the proofing ground, and Shoeburyness had unique advantages as a proof range.

The frequent air raids which took place over Woolwich from the autumn of 1915 onwards raised the question again in an acute form, output being seriously affected on many occasions. In this connection, however, it has been pointed out that in view of the present range and capacity of aircraft no part of the United Kingdom can be considered immune from aerial attack.

(c) *Lay-out and Development.*

Even before the war the lay-out of Woolwich was bad. The policy adopted in the past had been to add extensions to existing shops wherever there was room. It soon became impossible to consider whether the shop was in the right position, as regarded the work it had to do for other shops, or whether transport arrangements were reasonable or not. The shop had to be put where room could be found, and as this went on for many years the result was an accumulation of buildings most inconveniently disposed for manufacturing purposes, and the whole of the more western area became so congested that transport difficulties made economic production impossible. The difficulty was not so apparent when working with the small numbers employed in peace time, but after war broke out the effects of congestion became very marked. The policy of keeping the shops confined to the west end of the Arsenal continued after the war began, chiefly because none of the schemes of extension were on a sufficiently large scale to warrant breaking new ground, eastwards on the marshes, where the swampy nature of the soil presented great difficulty in making secure foundations. Extensions which were made to the Gun and Carriage Factory, shell factories and inspection buildings added to the congestion in this area. It was only some of the larger schemes such as the small arms ammunition factories, new fuse factories, and later the new gun factory and the Q.F. cartridge factory No. 4, and the woodwork departments which were moved out into more open ground. In these cases it was possible to get a good lay-out which resulted in greatly increased ease and economy of working. Further accommodation was required, soon after the out break of war, in the danger buildings, and this was provided by adding extra buildings in the existing enclosures, by which the fire risks were dangerously increased.

The Arsenal railways, like the buildings, had been laid out in a piece-meal fashion and though they served sufficiently well under peace conditions they soon proved inadequate to meet the demands made on them by the war pressure. Transport difficulties were enhanced by

the fact that two gauges were in use on the railways, standard gauge and 18-in. gauge, and in many parts of the Arsenal the line was laid as a combined gauge. The objections to this combined gauge were apparent before the war, and when traffic increased, the system became very difficult to work where the combined gauge was required to do duty for four lines, one up and one down for each gauge. By degrees additional sidings were added, and as far as possible all new lines were laid in standard gauge. The mileage at the beginning of the war was approximately 90 miles, and the total length of railway track constructed during the war was 44 miles of standard gauge and 15 miles of narrow gauge. The total length of new roads constructed was 13 miles. The unsatisfactory lay-out of the factories was one of the greatest troubles in connection with traffic, owing to the large amount of haulage necessary, since the same components had to travel in the course of manufacture to two or three stores which were often widely separated. At one time a large amount of traffic, mainly for the Deputy Director of Ordnance Stores, was being sent to the Arsenal, merely for issue and accounting purposes, but this traffic was stopped early in the war.

When the Ministry of Munitions took over control, traffic congestion at Woolwich was very serious. The difficulties were to a large extent overcome by re-arrangement of interdepartmental traffic, regulation of the traffic to the Arsenal, diversion of unnecessary traffic and by increasing the loading and unloading staff.[1]

Expansion in the Gun and Carriage Factories took place in three stages, the first on the outbreak of war, the second on the formation of the Ministry and the third at the beginning of 1917. The first urgent requirements were for 60-pdr. and 18-pdr. guns, 4·5-in. howitzers, carriages and vehicles of all descriptions, and a little later for 6-in. Mark VII guns on field carriages and 8-in. howitzers, converted from 6-in. guns. The extensions made at this time were not large because the space available was very limited; the most important was the taking over of a large two-storied inspection building and fitting it as a machine shop for sight work. With regard to the woodworking shops little could be done as there was no room for expansion, and the pressure was enormous. The inconvenient position of the saw mills on Frog Island added greatly to the difficulty, the only means of access being a single line railway bridge, with an almost equally narrow outlet. The work at this time was seriously affected by the breakdown of some of the ancient machinery, a large proportion of the old plant giving out and needing repair or replacement. The Gun Factory was able to cope fairly well with the demands made upon it at the initial stages of the war, but the Carriage Department was obliged to call in the help of outside firms, in the manufacture of the simpler parts of mountings. This course was rendered possible by the fact that jigs and gauges for almost all items of the work were available for supply to the firms undertaking manufacture.

[1] Hist. Rec./R/1122.11/2; *cf.* Vol. VII, Part V, Chap. II.

The second expansion in these Departments occurred on the formation of the Ministry of Munitions in 1915 and was caused by increased demands for 8-in. Mark VI howitzers, 60-pdrs., and 4·5-in. howitzers and their carriages. The Carriage Department having no room for extensions had still to rely on the trade to meet the new demands. At the same time it had to supply large numbers of stampings for the new R.L. fuse factory, and to meet this a large amount of additional stamping plant was put into No. 2 Foundry, which worked exclusively for the Royal Laboratory. In the Gun Factory two stores were turned into machine shops, though they were most unsuitable for the purpose; and machinery was installed in every available space in existing shops. The expansion in 1917 was caused chiefly by the large number of 18-pdr. and other guns coming from overseas for repair, and by the great demand for guns for arming merchant ships. For this purpose new shops were imperatively required. It was decided at the end of 1916 to erect new shops for the Gun Factory on the site of the existing timber sheds, part of which had to be pulled down owing to a fire, and to remove the whole of the timber sheds to a more suitable site on the marshes. On the site thus left vacant, a machine shop, forge and tempering shop were erected. This plant was designed to deal with the repair of 250 18-pdr. guns and to make 50 new 4-in. guns for the Navy per month.[1] It was begun in February, 1917, part of the machine shop was at work in October, 1917, and the whole was complete in February, 1918. Later on the saw mills were removed from Frog Island to a site on the marshes near the timber sheds and new wheelers, carpenters, and wood machining shops, drying houses and stores were erected concentrating the whole of the woodwork on one site. The cost of the work amounted to about £1,150,000.[2]

Shell filling was concentrated at the Arsenal until the spring of 1915, and the filling factories at Woolwich filled by far the largest proportion of the ammunition issued until the National Filling Factories started up in the summer of 1916. The demands upon Woolwich for filling and completing ammunition and filling components on the outbreak of war were enormous and great extensions were necessary in the Royal Laboratory. The total area added to the R.L. Factories was 1,520,572 sq. ft.[3] The filling capacity of Woolwich was considerably in excess of its output of empty ammunition and components and within the first week of the war, by the adoption of night-shifts and overtime, the melt plant, which normally filled 10,000 lbs. weekly and had never dealt with more than 30,000 lbs. increased its output to 100,000 lbs.[4] This plant was at first used solely for lyddite filling, that being the recognised high explosive filling in August, 1914. Great developments in the use of high explosives entailed the necessity for providing T.N.T. filling sections, and two came into operation in April, 1915, though the second was not actually completed until the following September. The lyddite plant had also been extended, and the ultimate capacity of the melt plant for both

[1] D.G.O.S./Woolwich/23.
[2] *Ibid.*
[3] Sec./Gen./802.
[4] *Ibid.*

explosives was estimated in July at 200,000 lbs. weekly. In the summer of 1915, three presses were installed to deal with 80/20 amatol, then used as a filling for 18-pdr. shell, and by the end of the year this plant was sufficient for dealing with 35,000 18-pdr. or 13-pdr. shells weekly.[1] The melt capacity was then 450,000 lbs. per week.[2] In September, 1917, an old lyddite factory was converted for filling naval ammunition with " Shellite " the method of filling having been worked out at Woolwich.[3]

In 1907, the Chief Superintendent of Ordnance Stores had become responsible for the storage of the stocks of high explosives which remained at the close of the South African War. The heavy pressure on the filling factories during the first two years of the war led to many additions to the danger buildings, and a corresponding increase in the expense magazines, which served not only the Ordnance Factory itself but also the riverside works which were engaged in completing ammunition. Full consideration to safety could not be given and it was considered that for a temporary expansion the increased risk was justifiable as a war risk. The magazines were mostly placed at a distance on the marshes and at Chislehurst, where some natural caves and dene holes had been acquired and adapted for the storage of explosives early in the war. Nevertheless, the question of danger at Woolwich caused considerable anxiety throughout the war. Explosives were stored on account of the Superintendent of Ordnance Stores, the Deputy Director of Ordnance Stores, and the Superintendent of Research, as well as for the use of the Filling Factories, and the works of riverside contractors. Of the 172 buildings which existed at the end of the war, each containing over 1 ton of explosive, only 15 complied with the regulations issued by the Home Office governing the distances which should be preserved between magazines and other danger buildings, and between these and private dwellings. There were 30 magazines and other buildings containing 3,562 tons of explosive situated within 100 yards of the river embankment and in many cases the distance was considerably less. A serious explosion might well have resulted in the flooding of the marshes. The small expense stores, many of which were unprotected by traverses or other adequate safeguards and were very close to the sheds in which large numbers of workpeople were employed, appeared specially dangerous. A fire in a shed, next one of the stores containing 15 tons of high explosive blistered the paint on the store walls, and it is worthy of note that the workers in the immediate locality, instead of flying from danger, heroically entered the store and busied themselves with removing to the centre of the shed the heavy boxes of explosives lining the walls. The general safety precautions which were enforced were, however, excellent and it was due to the extraordinary care with which these were enforced, and to the great knowledge of superintendents, managers and foremen of the nature of explosives, that Woolwich was immune from serious

[1] Hist. Rec./H/1520/6, p. 10 · D.D.G.(A.)9888.
[2] C.R./Filling/187.
[3] Sec./Gen./803.

explosions during the war. A great part of the difficulty arose on account of the large amount of filled ammunition which was stored at Woolwich, owing to the lack of accommodation elsewhere. It was found impracticable to do anything effective to improve the lay-out in this respect for some time, as the effects on production would have been too serious, but steps were taken to reduce the danger during the last months of the war.

From the beginning of the war the capacity of Woolwich for filling components was barely able to keep pace with demands, though extensive additions were made to the factories. Additions were made to the primer branch, cannon cartridge buildings, Q.F. cartridge factories and cap and detonator factories, entailing also a large increase of magazine capacity.[1] Three separate extensions to deal with fuses, gaines and minor components were begun in May, June and July, 1915.[2] New plant for a weekly output of 40,000 cases, 50,000 No. 83 fuses, 16,000 primers and 43,000 friction tubes was completed in the summer of 1916.[3] The extensions for filling both shells and components which were carried out during the latter half of 1915, included the erection of a new cartridge filling and assembly factory to double existing capacity. The extensions were designed to deal with the assembly of 100,000 18-pdr. shells weekly, either shrapnel or block filled.[4]

For the increased output of small arms ammunition extensions were also necessary. In September, 1914, an increase of at least 5,000,000 rounds a week was required, and sanction was obtained for buildings (factory C.F. 4) and plant for this purpose, and for increasing the output of shell fuses and cartridge cases.[5] In March, 1915, a proposal was put forward for a new factory working up to an output of 8,000,000 per week. The work was taken in hand in April, the factory being accommodated in certain existing buildings, formerly in the occupation of the Deputy Director of Ordnance Stores and the Chief Inspector, Woolwich.[6] In order to meet the heavy demands for ·303-in. Mark VII ammunition in the spring of 1916, a new factory with a capacity of 6,000,000 weekly was built at Woolwich in May (G.C.F. 2, afterwards known as C.F. 6).[7] The gauge shops at the Royal Laboratory were extended in August, 1916, by the addition of a large new shop.[8]

The developments described above were only the main extensions. The number and variety of the additions, which were made to the Royal Arsenal, the Dockyard and the Outstations maintained by the Chief Superintendent of Ordnance Factories during the war, can be

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[1] Sec./Gen./2239.
[2] C.R. 4436.
[3] 75/Gen./1982; 75/12/8967.
[4] D.D.G.(A.)9888, 12859.
[5] 75/14/1141.
[6] O.F./Gen./453.
[7] Vol. XI, Part VI, p. 51; *cf.* below p. 185.
[8] Vol. VIII, Part III, p. 15.

gathered from the list given in the footnote below.[1] A scheme for improving the lay-out of the Ordnance Factories was prepared in connection with the report of the committee referred to above.[2]

The supply of labour for the work of extension was difficult throughout the war, both as regards the quality and number of men employed. The difficulty was partially met by employing military labour and by obtaining navvies from Ireland. Building materials such as ballast, timber and steel were also difficult to obtain. A great deal of the building work in the Arsenal had always been carried out by direct labour, as the conditions under which it had to be performed so as to fit in with manufacture were such that it would have been almost impossible to arrange contracts. This was specially the case with work on the danger buildings. During the war the employment of direct labour was found to be the most speedy, though not the most economical method, since it would have been necessary had contracts been placed, to prepare plans and wait until the requirements of building were decided in considerable detail whereas by employing direct labour details could be arranged at the same time that work was proceeding.

(d) *Labour Problems.*

The pre-war policy of limiting the number of employees and staff at the Arsenal to a minimum, made the rapid and large expansion

[1] In 1914: August, additions to proof butts and magazines; September, additions to inspection building for S.A.A. and shell, to buildings for filling H.E. shell, to Royal Carriage and Gun Factories for field artillery equipment, erection of new S.A.A. factory (C.F. 4), new cannon cordite cartridge range, new buildings for H.E. filling, new shell and metal case factory, conversion of Chislehurst Caves as magazines, erection of storage sheds on the football ground and hutments for 50 married workmen at Plumstead; October-November, extensions to R.L. danger-buildings; December, new tailor's shop and paper shop. In 1915: March, two new 250-ton H.E. magazines, large storehouses; April, establishment of inspection and storage accommodation at Park Royal, expansion of A.O.D. stores as a new S.A.A. factory (C.F. 5) and erection of new A.O.D. stores on the marshes, construction of housing at Well Hall, new coaling pier and 200-ton crane; May, additions to danger buildings (fuse and gaine-filling); June, new bomb and grenade stores; July, new case and fuse factory, extension to shops for painting and examining shell; August, new Naval magazines; September, additions to inspection and proof buildings; erection of hutments; October, large new factory, for assembling Q.F. ammunition (Q.F. C.F. 4), additions to proof butts and railway sidings, erection of four 200-ton cordite magazines; December, additions to buildings for receiving and examining fuses, new hostels and additional hutments. In 1916: January, additions to naval stores, to Park Royal inspection buildings, to the Arsenal dining rooms and to C.F. 3 for making Japanese ammunition; February, 2 storehouses for components; March, additions to Research Department; April, extensions to filling and chemical shell factories and to proof butts, additional heavy gun gantry, new hostels for women; May, new S.A.A. factory (C.F. 6), additions to police quarters; June, additions to Park Royal storage, additional office accommodation for Inspection Department, new building for gun inspection, new Mekometer House, new powder magazine; July, additions to S.A.A. factory (C.F. 6); August, extensions to Tailors', Paper and Leather shops, extensions to Chemical Department Laboratory, new women's hospital; September, additions to gun inspection buildings, to Research Department,

[2] *See* p. 7.

required when war broke out a matter of great difficulty. The work was of a specially skilled nature and insufficient allowance had been made for staff to train the new men, who were in many cases mechanics of an inferior order. The staff had been barely sufficient to carry on, even in peace time, and when war broke out night shifts had to be formed at once, and principal and assistant foremen to be found. As the permanent staff could not be enlarged, all those engaged during the war were temporary and it was found that the institution of temporary foremen was a failure. They never really separated themselves from the men, or took up a similar position to that of the established foremen.

The rates of wages were those of the London district, but the normal working week at Woolwich was 48 hours as against 52½ to 54 hours elsewhere. A night shift allowance of time and a half after midnight was paid in addition to overtime, and Sunday work was paid double time throughout the 24 hours.

For the first two years of the war the hours worked at Woolwich were extraordinarily long. Cases occurred where men had worked 12 hours' shifts on 27 days out of 28, and women and boys on 13 days out of 14. Women were frequently employed on 7 consecutive night shifts, normally of 12 hours. Men on overtime had sometimes worked up to 96 hours per week and boys up to 75.[1] Taking into account the comparative shortness of the normal working week and the overtime

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and to Experimental Signals Establishment, new gauge shops, new storage depôt; October, additional storage accommodation and Bond Stores, additional accommodation at railway sidings and new railway halt, additional dining room for women; November, new telephone exchange, new inspection building, new landing stages and ferry, additions to Gun Factory and Carriage Department and to dining rooms at Dockyard; December, extensions to shell store. In 1917: January, additional inspection offices, new store and dining room at Dockyard; February, extension of proof ranges; March, extension of Chemical Shell Factory, provision of electrical furnaces and connecting mains, conversion of quarters into offices at Pimlico; April, extension to Research Department, new dining room for boys; May, cloak-room accommodation at S.A.A. Factory; June, new dining room, new offices and shops for D.I.O.S.; July, offices for Inspection and Army Ordnance Departments; August, extensions to Research Department; September, rebuilding store at Q.F.C.F. 4; extension of empty shell sheds; new shellite factory in Cartridge Case Factory, adaptation of building at Raynes Park as Signals Factory; October, extensions to Signals Experimental establishment, alterations and additions to Signals factory, Teddington; November, new Battery Room at Dockyard, reconstruction of storehouse B. 37; December, conversion of H.E. buildings for amatol filling, new furnaces for destroying cartridges and building for breaking down enemy ammunition. In 1918: January, new shed for returned ammunition, additions to shifting house accommodation for trotyl workers and to accommodation for inspection and storage of naval components; February, foul drainage system for Magazine Area; March, buildings at Cricklewood adapted for Signals Factory, new dining room at Research Department, extension of R.A.C.D. Depôt, Battersea Park, new heating installation for A.O.D. Stores; May, alterations to R.A.C.D. Depôt, Old Kent Road; July, alterations and additions at Battersea Park R.A.C.D. Depôt; September, alterations and additions at Marylebone and Fetter Lane Clothing Depôts; October, extensions for amatol filling, new buildings for cleaning cartridge cases.

[1] Vol. V, Part III, p. 88.

allowance rising from time and a quarter to time and a half at the end of 2 hours, it is not surprising that exaggerated accounts of the wages obtained by Woolwich employees obtained circulation. A scrutiny of the wages earned at Woolwich for the quarter ending 5 July, 1918, revealed the fact that out of a total of about 66,600 employees, 427 earned an average of £10 a week or more. Of these, 205 were employed in the Gun Factory, 119 in the Small Arms Ammunition factories, 52 in the Carriage Department and 49 in the East and West Laboratory.[1]

Dilution of labour at Woolwich was begun when Sir Vincent Raven became Acting Chief Superintendent in August, 1915. The pre-war policy of employing boy labour had been continued until this time. It was, however, found to be inefficient, not only actually as compared with female labour, but on account of the constant turn over of boys, 1,400 having left during the first year of the war. The cartridge machines were run by boys, and a comparison of the overall efficiency of the various machines used in the operation with the efficiency of the six best boys showed a low general efficiency.[2] During the summer of 1916 men were being released for the Army at the rate of about 250 per week. In the Gun and Carriage Department female labour was not at once adopted but gradual dilution was effected by training a very low grade of mechanic for the high class work required in these factories. This was thought to be a better method than the introduction of women into work for which their fitness was questionable. Sir Vincent Raven was of the opinion that it was of primary importance that dilution should be effected independently of outside intervention, and by methods which should recommend themselves as suited to the peculiarities of the case. During the period in which he had been in control at Woolwich there has been no strikes, but situations had frequently arisen which required very delicate handling, and he considered that outside interference might involve very serious consequences.[3] The excellent relations between the authorities and the men were evidenced by the fact that the Chief Superintendent was accepted as the final arbiter in any questions arising from the dilution agreement. When Sir Vincent Raven first took control over the Arsenal in August, 1915, the total number of employees included no women and was 34,000. In November 1916 this number had risen to 68,000, and during that time 11,000 men were released to the colours, their places being taken by women: 20,000 women had been engaged. By May 1917 the number of employees had increased to 74,467 and there were between 25,000 and 26,000 women.[4] Dilution took place principally in the Royal Laboratory, the work of the Gun and Carriage Department being less suited to women. In the Small Arms Ammunition Factories, the percentage of skilled men was reduced from the pre-war figure of 18·3 to 15·2 in September 1916, and to 10·3 in September 1918.[5]

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[1] Sec./Gen./804.
[2] O.F./C/6.
[3] C.R. 4551.
[4] Hist. Rec./R/1122.11/19.
[5] Sec./Gen./803.

The following figures show the dilution effected in the chief factories by August 1918.[1]

Factory.	Males. Under 18.	Males. Over 18.	Females.	Total.
Carriage Department	444	5,071	23	5,538
Gun Factory	113	3,569	146	3,828
East and West Laboratory	680	8,593	3,713	12,986
S.A.A. Factories	1,004	3,171	5,545	9,720
Filling Factories	1,071	8,032	11,692	20,795

The following figures show the numbers employed in the Arsenal during the war and the rapidity of its growth.[2]

Date.	Men.	Women.	Boys.	Total.
1 August, 1914	9,466	125 [3]	1,275	10,866
2 January, 1915	19,378	194 [3]	3,059	22,631
4 December, 1915	37,749	609	7,540	45,898
13 May, 1916	44,025	8,104	7,704	59,833
30 December, 1917	41,000	25,700	6,000	72,700
31 May, 1918	38,374	22,338	4,265	64,977
2 August, 1918	37,895	24,018	3,549	65,462

The questions of housing and transport to and from the Arsenal of the increasing numbers of employees became very serious. Woolwich had before the war been greatly overcrowded, and with the influx of some 60,000 new workers into the Arsenal the pressure became very great. A garden suburb of 12,000 houses was built at Well Hall early in 1915 by the Office of Works. Seven estates of bungalows were developed providing at the end of 1918 for 2,654 families, and residential hostels were erected to accommodate 750 boys, 2,600 women and 2,000 men.[4] During 1915 and 1916 the difficulty of getting to and from the Arsenal was found to be one of the most serious causes of fatigue to the workers. The establishment of a river ferry, the arrangement of better tram, omnibus and railway services and the careful arrangement of shifts remedied this to a certain extent. The shifts were arranged to distribute the passengers to and from the Arsenal as far as possible at intervals during the 24 hours. The congestion of traffic and housing made it impossible to introduce three 8-hour shifts, as this would have necessitated a large addition to the number of workers. The arrangements for facilitating transport at Woolwich have been described in detail elsewhere.[5] All municipal duties at the Arsenal increased greatly with the increasing number of employees. Before the war few facilities existed for providing meals in the Arsenal. At the end of the war the total number of employees numbered some 100,000 and 72 dining rooms and short meal buildings had been

[1] Sec./Gen./802.
[2] Vol. V, Part III, p. 157; HIST. REC./R/1122.11/19.
[3] Employed on home work for the Arsenal.
[4] Vol. V, Part III, p. 157.
[5] Vol. V, Part V, p. 43.

provided.[1] The disposal of refuse and sanitary conditions generally involved a large increase in the duties of the Building Works Department.

(e) *The Nature and Quantity of the Factories' Work.*

The most striking feature about the output of the Woolwich Ordnance Factories during the war is the extraordinary diversity of the stores produced. Throughout the war the specialised skill and machinery of Woolwich were invaluable both for producing experimental and special types required in comparatively small quantities, and for meeting specially urgent demands. Plant was subject to constant changes to meet these demands, and continuity of output was almost unknown. Almost every kind of ammunition and its various components were manufactured at Woolwich, and the filling factories had to deal with the same variety of work, lyddite, T.N.T., fulminate of mercury, gun cotton, shellite, explosive for explosive bullets, and for a short time with gas shell. It was not unusual for the factories to have 300 items on the weekly programme, while 30 or 40 would be quite a large number for a national factory.[2] The Gun and Carriage Factories were at times dealing with 20 different types of guns. Woolwich programmes were also constantly liable to dislocation on account of the adjusting function which the Ordnance Factory performed in the general supply programme. Special instructions were constantly received to hasten certain orders in order to remedy a shortage. This continued throughout the war, but the adjusting process was specially imperative and frequent in the early years of the war before the supply of munitions was organised and co-ordinated. Experimental and special orders continued throughout the war, for Woolwich with its experienced staff and close touch with the Superintendent of Research, the Superintendent of Experiment, the Inspection Department, and Ordnance Committee was specially fitted for this work, and its concentration at Woolwich avoided dislocation in the national factories which were turning out stores in bulk on a repetition basis. Another special item in the Woolwich programme was the repair work done there. Damaged guns which required repairs of a difficult or intricate nature were subjected to special examination and report by the Chief Superintendent or his officers, and the experience gained was often of value in subsequent design.

Until the spring of 1915 all high-explosive shells were filled at Woolwich, and the greater part of this class of work was done there until April, 1916, when the national filling factories were in a position to begin output on a large scale. The output of complete small arms ammunition increased from about 28,750,000 in August-December, 1914, to 284,000,000 in 1915, and 418,000,000 in 1916[3] while the output of cartridges made by the trade and filled at Woolwich was about 803,000 during August-December, 1914, over 4,250,000 in 1915, and

[1] For a general account of the work in relation to welfare, *see* Vol. V, Part III, pp. 157-161.
[2] Sec./Gen./2239.
[3] Exclusive of Japanese and Russian ammunition and of ball ammunition.

9,000,000 in 1916. The Ministry remained dependent on Woolwich throughout the war for filling certain heavy gun shell and cartridges, and for all shell and complete rounds required for proof of fuses and practice, as well as for the bulk of ammunition required for anti-aircraft purposes, the filling of base percussion tubes and certain special primers and tubes; but at the end of the war Woolwich filled only about 7 or 8 per cent. of the total requirement of complete gun ammunition for the land service. On the other hand, the Admiralty depended on Woolwich for practically the whole of its filling during the war.[1]

During the first eighteen months of the war, the Woolwich output of shell and components represented a large percentage of the total. The output of empty shell increased from 124,562 in August to December, 1914, to 1,218,997 in 1915, and 1,749,577 in 1916, the output reaching a maximum in that year. The empty shell filled at Woolwich reached a maximum of 6,810,103 in the same year. At the end of the war the shell supply from Woolwich for land service was comparatively small. The cartridge case supply was 15 per cent. of the total, though in certain special natures it was 50 per cent. of the whole. For fuse manufacture Woolwich capacity was about 5 per cent. of the whole. Output was chiefly concentrated on Nos. 83 and 44, and in respect of these natures represented about 40 per cent. of the total capacity of the country.[2]

The gun programme at Woolwich, as regarded land service guns after 1916, was a very varying and diminishing one. The extent to which the Ministry relied on Woolwich for guns depended greatly upon Admiralty requirements, and it was often necessary for the Admiralty to absorb productive capacity normally available for land work, which then had to be transferred to other factories. The Admiralty had a preference for Woolwich, since their demands were usually of an urgent nature.[3] Moreover, practically all the new guns for the naval service were designed at Woolwich. Roughly, 75 per cent. of gun designs prepared at Woolwich were for the naval service, the remainder being divided between the land service and Royal Air Force. The total production of guns of all descriptions and for all services during the war was 4,326. The expansion during the first two years of war was very rapid. From August to December, 1914, 126 guns were produced, chiefly 6-in., 3-in. Q.F., 18-pdr., and 4·5-in. howitzer. The total figure for 1915 was 694, a large number of which were 18-pdr. and 4·5-in. howitzers. In 1916, 931 guns were produced, chiefly 60-pdr., 3-in., and 4·5-in. howitzers. A further great expansion took place in 1918, after the extension of the gun factory. The total production was 1,638, of which the greater number were quick-firing guns of various types. In addition to these guns a number of trench howitzers were produced during 1915 and 1916, and repairs and conversions accounted for the large total of 5,434. The miscellaneous productions of the Gun Factory formed a large item in its general production, and varied from important components such as breech

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[1] C.R./Filling/384. [2] HIST. REC./R/1122.11/19. [3] *Ibid.*

blocks, pinions and aiming rifles to small parts such as springs, washers, keys and levers.

The production of the Carriage Department included, besides gun carriages and limbers, carts and wagons and travelling kitchens. The expansion during 1915 was enormous, the issues increasing from 1,388 during the last five months of 1914 to 7,769 in 1915. In 1916 the output of new carriages, etc., dropped to 4,939 and decreased during 1917 and 1918, the Carriage Department being largely occupied during 1917 and 1918 in repair work. The total of carriages, limbers, gun mountings, carts and wagons repaired in 1917 was 6,066, out of a total of 9,528 during the whole of the war period. The total of miscellaneous productions of the Carriage Department during the war period amounted to 8,985,925 items.

The tables of output which follow give some idea not only of the enormous quantity of the stores produced at Woolwich, but also of the extremely miscellaneous character of the work which was done there during the war.

TABLE I.

Issues from the Royal Gun Factory, Woolwich, August, 1914, to December, 1918.[1]

(*a*) Ordnance Manufactured.

Description.	1914. Aug.–Dec.	1915.	1916.	1917.	1918.	Total.
Ordnance B.L. 15-in.	2	9	11	6	3	31
,, ,, 14-in.	—	—	—	2	—	2
,, ,, 13·5-in.	—	7	1	—	—	8
,, ,, 12-in.	—	—	3	1	—	4
,, ,, 9·2-in.	2	2	—	—	—	4
,, ,, 7·5-in.	—	—	—	8	1	9
,, ,, 6-in.	35	43	33	22	86	219
,, ,, 60-pdr.	—	88	168	—	46	302
,, ,, 4·7-in.	—	—	—	24	52	76
,, ,, 4-in.	—	1	14	9	—	24
,, ,, 2·75-in.	4	—	6	—	—	10
,, Q.F. 3-in.	26	46	182	160	333	747
,, ,, 4-in.	9	93	82	433	521	1,138
,, ,, 18-pdr.	11	177	12	—	180	380
,, ,, 13-pdr.	6	1	5	108	52	172
,, ,, 12-pdr.	1	8	76	62	265	412
,, ,, 6-pdr. (Sub. cal.)	—	30	17	3	—	50
,, ,, 3-pdr. (Vickers)	—	16	29	—	—	45
,, ,, 3-pdr. (Sub. cal.)	—	30	27	—	—	57
B.L. Howitzer 8-in.	—	—	—	20	—	20
,, ,, 6-in. 26-cwt.	—	—	91	9	—	100
Q.F. ,, 4·5-in.	30	143	174	68	99	514
,, ,, 3·5-in.	—	—	—	2	—	2
Grand Total ..	126	694	931	937	1,638	4,326 [2]

[1] Compiled from Hist. Rec./H/1122·1/2, 3.
[2] Of these 4,168 were complete with breech fittings.

(b) TRENCH HOWITZERS MANUFACTURED.

Description.	1914. Aug.-Dec.	1915.	1916.	1917.	1918.	Total.
Ordnance R.M.L. Trench Howitzer 4-in.	12	50	238	—	—	300
Ordnance M.L. Trench Howitzer 3·7-in...	—	320	151	—	—	471
Ordnance R.M.L. Trench Howitzer 2-in.	—	126	2	—	—	128
Total	12	496	391	—	—	899

(c) ORDNANCE REPAIRED OR CONVERTED.

Description.	1914. Aug.-Dec.	1915.	1916.	1917.	1918.	Total.
Ordnance B.L. 15-in.	—	30	6	1	2	39
,, ,, 13·5-in.	3	18	6	8	1	36
,, ,, 12-in.	20	27	21	16	17	101
,, ,, 9·2-in.	4	7	25	23	14	73
,, ,, 7·5-in.	—	1	3	1	1	6
,, ,, 6-in.	56	85	46	80	70	337
,, ,, 6-in. converted to 8-in. How.	—	24	—	—	—	24
Ordnance B.L. 4-in.	8	11	4	53	2	78
,, ,, 60-pdr.	2	25	96	228	144	495
,, B.L.C. 15-pdr.	5	14	25	3	6	53
,, B.L. 12-pdr. 6-cwt. ..	—	5	—	1	—	6
,, B.L. 2·75-in. ..	—	—	2	—	—	2
,, ,, 10-pdr. .. (jointed).	2	2	3	1	—	8
,, ,, 9·2-in. How.	1	—	1	—	—	2
,, ,, 8-in. ,,	—	1	—	27	1	29
,, ,, 6-in. 30-cwt. ,,	26	60	21	16	—	123
,, ,, 6-in. 26-cwt. ,,	—	—	—	42	8	50
,, ,, 5-in. ,,	6	20	33	1	—	60
,, Q.F. 6-in. ..	1	11	34	1	1	48
,, ,, 4·7-in. ..	104	193	211	68	20	596
,, ,, 4-in. ..	60	26	14	4	8	112
,, ,, 3-in. ..	—	—	1	23	48	72
,, ,, 18-pdr. ..	18	7	203	1,028	318	1,574
,, ,, 15-pdr. ..	10	40	4	2	—	56
,, ,, 13-pdr. 9-cwt	—	—	1	166	130	297
,, ,, 13-pdr. ..	6	64	80	33	18	201
,, ,, 12-pdr. 18-cwt	—	—	—	3	—	3
,, ,, 12-pdr. 12-cwt	4	15	76	11	6	112
,, ,, 12-pdr. 8-cwt	2	5	3	—	—	10
,, ,, 4·5-in. How.	29	1	16	113	5	164
,, ,, 6-pdr. .. (Hotchkiss)	8	24	63	6	—	101
,, ,, 3-pdr. .. (Hotchkiss)	8	17	60	8	11	105
,, ,, 6-pdr. .. (Nordenfeldt)	—	54	11	42	5	112
Carried forward ..	383	787	1070	2009	876	5085

Ordnance Repaired or Converted—*cont.*

Description.	1914. Aug.–Dec.	1915.	1916.	1917.	1918.	Total.
Brought forward ..	383	787	1070	2009	876	5085
Ordnance,						
Q.F. 3-pdr. .. (Nordenfeldt)	—	2	—	—	—	2
„ „ 6-pdr. .. (single tube)	—	—	4	1	5	10
„ „ 6-pdr. .. (Sub. cal.)	1	28	38	29	15	111
„ „ 3-pdr. .. (Sub. cal.)	1	41	11	16	7	76
„ „ 3-pdr. .. (Vickers)	2	5	8	2	—	17
„ „ 77-mm. ..	—	—	—	16	46	62
Total	387	863	1,131	2,073	909	5,363

(*d*) Trench Howitzers Repaired or Converted.

Description.	1914. Aug.–Dec.	1915.	1916.	1917.	1918.	Total.
Trench Howitzer, 4-in.	—	2	—	—	—	2
„ „ 3·7-in.	—	56	4	2	—	62
„ „ 240-mm.	—	—	—	4	—	4
Total	—	58	4	6	—	68

(*e*) Miscellaneous Production.

Gun and Howitzer Fittings.

Component parts, important items, viz. :—breech blocks ; carriers ; frames, breech mechanism ; pinions, intermediate and crank ; rifles, aiming ; screws, breech ; vents, axial	4,899
Component parts of minor importance, viz. :—actions ; arcs, control ; attachments ; bearings, ball ; blocks (various) ; bolts (various) ; boxes (various) ; brackets (various) ; buffers ; bushes (various); catches (various); clamps ; collars (various) ; counterweights ; cranks (various) ; cutters; cylinders, anti-fouling ; discs (various) ; extractors (various) ; firing mechanisms ; firing pieces ; frames (various) ; gear, hand operating ; guides (various) ; hammers, firing ; hard steel pieces ; keys (various) ; latches (various) ; lever shafts ; levers (various) ; links (various) ; lubricators ; needles (various) ; nuts (various) ; obturators (various) ; pads (various) ; pieces, filling (various) ; pinions (various) ; percussion firing gears (various) ; plates (various) ; rings (various) ; plugs ; plungers ; screws ; sights (various) ; sleeves (various) ; sockets (various) ; spindles (various) ; springs (various); stirrups, hammer firing; stops, safety (various) ; strikers (various) ; studs ; tappets, lever trigger ; toe pieces for locks ; tommies (various) ; triggers (various) ; vents (various) ; washers (various) ; wedges (various) ; wires (various)	177,925
Forgings, castings and stampings in connection with the above ..	8,052

Implements, Gauges and Accessories.

Adapters (various); apparatus, testing; bits, vent; blocks (various); borers, tube chamber; boxes (various); breech mechanisms; bushes; cases (various); clamps; clearers, vent; cutters; cutters and punches; discs; drifts (various); gauges (various); guides; hammers, lead; instruments, taking impressions bore; machines (various); presses, obturator; rimers, breech; rods, measuring; scrapers, ordnance; sectors; springs, gauges crusher; tools (various); wrenches (various)	37,348
Castings and forgings in connection with implements, gauges and accessories	131
Heavy Forgings.	
"A" tubes, Q.F. 4·7 in.; jackets, Q.F., 18-pdr.; short bores and chamber liners, Q.F., 18-pdr. and 13-pdr. Q.F. 4·7-in., B.L. 60-pdr.; inner "A" tubes, B.L. 60-pdr., B.L. 6-in.; "A" tubes, Q.F. 18-pdr. and 13-pdr., B.L. 6-in., B.L. 8-in. How.; short bores and chamber liners, B.L. 6-in.; Q.F. 3-in. Q.F. 12-pdr.; inner "A" tubes, B.L. 6-in.; inner "A" tubes, B.L. 4-in.; inner "A" tubes, B.L. 12-in.; inner "A" tubes, B.L. 9·2-in.; jackets Q.F. 3·7-in. How.; jackets Q.F. 4·5-in. How.; "A" tubes, Q.F. 3·7-in. How. (muzzle and breech), Q.F. 4·5-in. How. Q.F. 3-in.	1,819
Wireless Telegraphy parts of	7,526
Operations for Contractors.	
Jackets Q.F. 18-pdr. rough turned, rough bored and machined; treating forgings for inner "A" tubes B.L. 9·2-in. supplied by contractors; treating steel forgings for Q.F. 6-pdr. wedges blocks	185
Accessories supplied to French Government and to various Firms.	
Completing forgings of discs, breech, rifle, aiming, from the Anglo-Russian Engineering Company; making and supplying jigs and gauges to guide manufacture of obturators; and making and supplying for French Government obturators (various) and discs, adjusting	1,420
Total	239,305

In addition to the above the following very small accessory articles were made during the same period :—

Coppers, gauges (various)	1,000,890

(*f*) MISCELLANEOUS REPAIRS.

Repairs to component parts of Breech Fittings, etc., viz. :—Blocks, breech; boxes; carriers; locks, electric; mechanisms; obturators; rings; screws, breech; sights; strikers; vents	11,679
Repairs to Aiming Rifles and Morris Tubes	910
Forgings, viz. :—Breech rings; jackets; inner tubes; liners	461
Total Items	13,050

TABLE II.

Issues from the Royal Carriage Department, Woolwich, August, 1914, to December, 1918.[1]

(*a*) Carriages, Limbers, Gun Mountings, Carts and Wagons Manufactured.

Description.	1914. Aug.–Dec.	1915.	1916.	1917.	1918.	Total.
Carriages, Field, Siege and Travelling (various) for Guns from B.L. 2·75-in. to B.L. 8-in. How.	88	504	336	225	228	1,381
Carriages, Garrison (various) for Guns from Q.F. 4-in. to B.L. 9·2-in.	—	2	17	1	4	24
Carriages, Naval	—	—	129	182	447	758
Carriages, Proof	2	—	—	—	—	2
Limbers, Carriage (various) for Guns from Q.F. 13-pdr. to B.L. 8-in. How.	64	2,047	1,620	1,588	1,253	6,572
Gun Mountings for Guns from Machine-gun ·303-in. to Q.F. 13-pdr.	196	442	214	243	529	1,624
Carts (various) including Kitchens	490	1,432	394	133	358	2,807
Wagons (various)	548	3,342	2,229	1,027	693	7,839
Total	1,388	7,769	4,939	3,399	3,512	21,007

(*b*) Carriages, Limbers, Gun Mountings, Carts and Wagons Repaired.

Description.	1914. Aug.–Dec.	1915.	1916.	1917.	1918.	Total.
Carriages, Field, Siege and Travelling for Guns from Q.F. 1-pdr. to B.L. 8-in. How.	136	191	86	273	310	996
Carriages, Garrison, for Guns from Q.F. 6-pdr. to B.L. 6-in.	22	51	66	46	36	221
Limbers for Guns from Q.F. 1-pdr. to 9·45-in. How.	187	213	84	277	108	869
Mountings from tripod for Guns from Machine-gun ·303-in. to 3-in. H.A.	45	30	41	5,014	1,211	6,341
Carts (various)	31	63	2	31	123	250
Wagons (various)	163	119	60	425	84	851
Total	584	667	339	6,066	1,872	9,528

[1] Compiled from Hist Rec. /H/1122.1/2, 3

(c) MISCELLANEOUS ARTICLES MADE.

Major items, viz. :—adapters (various) ; axle trees (various) ; beds for trench howitzers ; buffers (various) ; capstans, crab ; cradles (various) ; drugs (various) ; frames, crab, for hoisting guns 50 and 25 tons ; gear for correcting automatic sights ; gyns, triangle ; holdfasts (various) ; loading teachers (various) ; lorries, aeroplane ; pedestals, carriage ; platforms, travelling and firing ; pumps, air or liquid ; recuperators ; screens for velocity experiments ; sleighs, gun	2,441
Minor items, viz. :—adapters, cradle ; apparatus, adjusting and testing (various) ; arcs, traversing ; attachments ; axles ; bags (various) ; banderols ; bandoliers ; bands, canvas (various) ; barrows (various); bases, pole for tents, marquee ; baskets, ammunition (various) ; battens ; baulks ; beams ; bearers (various) ; blocks (various) ; boards (various) ; brushes (various) ; buckets (various) ; buoys ; bushes (various) ; buttons, wood, tent ; calculators, range ; cans (various) ; caps (various) ; carriers (various) ; cartouches ; catches ; chesses, pontoon ; clamps ; cleaners (various) ; clinometers ; coatings ; connectors ; correctors ; couplings, pontoon ; cradles ; camp kettles ; cylinders (various) ; davits ; derricks ; discs ; drifts ; drivers ; drums, iron and wood ; ejectors, projectile ; eyes, lifting ; extractors (various) ; felloes, sand ; fittings (various) ; frames ; funnels (various) ; gauges (various) ; gear, clamping ; grabs ; gunwales, pontoon ; handles (various) ; handspikes (various) ; heads (various) ; holdalls ; holders ; holdfasts ; hooks ; indicators (various) ; jacks ; kegs, paint (various) ; levers (various) ; lids ; lifters ; mallets (various) ; measures ; panniers ; pickets ; pipes ; pistol grips ; planks (various) ; plates ; plotters ; pockets ; pumps ; racks ; rammers (various) ; rectifiers ; reflectors ; ribands ; ribs, pontoon ; rings ; rods (various) ; rollers (various) ; ropes (various) ; rowlocks, pontoon ; rules (various) ; runners ; saddles (various) ; screw-drivers ; scotches (various) ; selvagees ; setters ; shafts (various) ; spars ; shields (various) ; shoes (various) ; sights, fore, tangent and telescopic ; slings (various) ; spanners ; sponges ; stanchions ; stands, portable for machine guns in torpedo boat destroyers ; staves (various) ; sticks ; straps ; swingletrees ; syringes ; tools ; trailers ; tampeons ; tanks, oil ; transoms ; trays (various) ; targets ; trestles ; trolleys ; uprights for firing sound pockets ; vases, tent ; washers ; wedges ; wrenches	1,292,841
Aprons, bags, covers (various), and hoods	66,480
Barrels (various), and kegs	22,336
Boxes (various)	1,085,943
Cases (various)	464,860
Chests (various)	14,171
Labels, line (various)	3,552,553
Pegs, picketing with rope loop	331,940
Packing pieces (various)	988,323
Pins, lynch (various)	17,773
Pins, tent	523,700
Plugs (various)	321,639
Poles, posts and props	268,603
Sights (various), including automatic and naval	7,593
Skids (various)	9,052
Wheels (various)	15,677
Total	8,985,925

(d) MISCELLANEOUS ARTICLES REPAIRED.

Barrels, powder ; boxes (various) ; cases (various) ; chests ; dischargers, grenade ; felloes ; gauges ; indicators, fuse ; jacks, lifting ; motor chassis ; packsaddlery ; pedestals, carriage ; platforms ; plugs ; sights (various) ; slugs, projectile ; wheels	4,318,205

TABLE III.

Issues from the Royal Laboratory, Woolwich, August, 1914, to December, 1918.[1]

(*a*) Annual Output of Principal Stores.

Description.	1914. Aug. to Dec.	1915.	1916.	1917.	1918.	Total.
Bombs (various), complete— Manufactured and Filled	1,913	20,349	30,868	18,456	2,872	74,458
Filled only	—	3,879	28,134	31,545	82,810	146,368
Cartridges— Q.F. 3-in. to 4·7-in.— Manufactured and Filled	11,939	11,878	138,279	260	27,032	189,388
Filled only	802,990	4,341,608	9,064,342	14,141,415	10,343,872	38,694,227
Drill, Q.F. 18-pdr. to 6 in.	626	17,223	11,625	3,678	5,195	38,347
Gun, B.L., R.M.L. and S.B. 3-pdr. to 14-in., filled	127,602	738,657	1,350,645	2,096,295	2,924,390	7,237,589
Small Arm— (Short, Rifle Grenade, Tracer, Armour-piercing Buckingham), complete	28,783,300	284,009,747	418,000,896	298,384,943	347,348,776	1,376,527,662
·303 Ball, complete ..	1,440,205	2,613,695	1,042,241	4,007,280	3,732,518	12,835,939
Pistol, Webley, Ball ..	—	—	83,191,538	79,738,562	—	162,930,100
Japanese	—	—	155,400	24,495,508	16,192,117	40,843,025
Russian	—	—	4,000	125,320,902	351,600	125,676,502
Impulse, Torpedo, complete	—	17,800	12,524	20,547	26,692	77,563
Fuses— Manufactured and Filled	219,010	1,085,422	2,228,174	3,456,621	975,216	7,964,443
Empty	—	—	—	331,283	3,036,962	3,368,245
Filled only	—	960,678	16,002,975	19,482,924	14,840,339	51,286,916
Shells— Empty	124,562	1,218,997	1,749,577	1,536,942	1,217,327	5,847,405
Filled only	233,207	2,094,379	6,810,103	6,181,377	4,591,248	19,910,314
Drill	21	261	25	90	1,221	1,618
Dummy	64	1,208	109	193	82	1,656
Star-Shells, Filled only ..	—	294	86	5,879	34,284	40,543
Trench Howitzer Ammunition— Bombs	545	189,515	156,652	5,388	—	352,100
Charges	—	30,743	25,584	31,852	—	88,179
Components	—	308,713	32,261	804	—	341,778
Totals ..	31,745,984	297,665,046	540,036,038	579,292,744	405,734,553	1,854,474,365

[1] Compiled from Hist. Rec./H/1122·1/1.

(b) Aggregate Output of Secondary Stores.

Description.	Total during the War.
Components, Bomb—	
Manufactured	1,072,267
Filled only	725,673
Components, Cartridge—	
Q.F. Manufactured	927,215
B.L. Manufactured	128,727
B.L. Filled only	133,526
Components, Shell—	
Adapters ; bags, burster ; bags, primer ; bandoliers, cotton ; caps, false, steel ; flash reducing charges for 4·5-in. How. ; gaines.	30,675,878
Components for Shell Filling	732,480
Detonators	1,725,370
Exploders	8,384,991
Mines—	
Empty	429
Filled	41,996
Sweeping Charges	10,863
Depth Charges (Filled only)	6,566
Counter Mines (Filled only)	64
Shot—	
Proof 1-pdr. to 15-in.	13,194
Case, 6-pdr.	1,997
Practice, 2-pdr. to 13·5-in.	46,931
Paper, 4·7-in. and 12-pdr.	520
Tracers, Shell, Night, External and Internal—	
Manufactured and Filled	739,337
Filled only	343,821
Dummy	28,157
Composition for Bullets (in lbs.)	135,438⅜
Cement, various (in lbs.)	177,265¾
Match, quick (in yds.)	2,162

(c) Miscellaneous Articles Manufactured.

Bags, primer, filled belt; cases, guncotton; cases, powder; components of cases; components of exploders; components of fuses; components of S.A. cartridges; components of mines; containers, copper and aluminium; copper gauges; covers, cartridge; cushions, powder barrel; cylinders, guncotton; discs for lyddite shells; driving-bands; extractors (various); fuses, converted; fuses fitted with gaines; guncotton, wet, charges; igniters, torpedo (filled only); implements, ammunition; lanyards; levers; lights; links, belt M.G.; litmus paper; machines, rocket; machines for weighing cartridges; mouth-pieces for cylinders, G.C.; pieces, packing, copper, for boxes, guncotton; plates; plugs; pockets; portfires; primers; protectors; parachutes for star-shells; puffs, cordite and powder; pumps, air; rectifiers, guncotton, primers; rings, augmenting; rockets; screws; shot, rear for Davis gun; sockets; strips, augmenting; spanners; torpedo warheads, charges (various); tubes (various), made and filled, empty, filled only; tubes, electric, wireless, for torpedo dropping gear 297,525,977

(*d*) Repairs.

Description.	Total during the War.
Naval Ordnance Stores—	
Bombs, all patterns	12,530
Cartridges :	
B.L. 4-in. to 15-in.	3,636
Q.F. 1-pdr. to 6-in.	382,927
Q.F. Cases	3,310,099
Cases, powder	156,708
Shell, all patterns	70,965
Land Service Stores—	
Bombs, and Bombs Carcass	5,545
Cartridges :	
B.L. Filled	138,406
R.M.L. and B.L. (Filled) examined, broken down, etc.	100,504
Q.F. Empty	1,069,945
Q.F. (Filled) broken down and re-made	2,922,950
Q.F. Cases, empty	3,101,001
Q.F. or Q.F.C. Adapters	1,466,355
Cylinders, cartridge	494,069
Plugs	4,235,439
Primers :	
Percussion, etc.	1,487,990
Electric, Large, etc.	16,975
Shell, empty, 1-pdr. to 15-in.	340,448
Miscellaneous Repairs	2,789,860

III.—The Royal Small Arms Factory, Enfield Lock.

(a) *Preliminary.*

The Royal Small Arms Factory at Enfield was established in 1804, when the country was threatened with invasion and the Government was almost entirely dependent on foreign muskets for arming the regular troops and the volunteers. Until 1854 the establishment was on a very restricted basis, and was occupied mainly with such work as the conversion of the flint-lock to the percussion musket, the manufacture of swords, repairs and the "setting-up" or assembling of a comparatively small proportion of the musket parts, for which contracts were placed in industrial districts. In that year a very considerable extension was made for the manufacture of rifles by machinery. The extension was the outcome of delay experienced in obtaining the new Minié rifle from the trade during the year 1853. The Master-General of the Ordnance (Lord Raglan) accordingly planned the establishment of a large government rifle factory to provide the whole of the British forces, independently of the trade. This factory was to have been erected at Woolwich and to have replaced the outlying establishments at Birmingham, Enfield and the Tower, where certain operations in the manufacture or repair of muskets were then being carried out. At the

recommendation of a select committee, which considered the cheapest and most efficient method of making small arms, this larger project was modified and a comparatively small factory was built at Enfield to serve as an experiment in the advantages to be derived from the more extensive application of machinery, as a check upon contractors' prices and as a resource in time of emergency.

The new rifle factory was complete by 1858, and consisted of two main divisions, the smithery, having about 45 forges, and the department for rolling and perfecting the rifle barrels. Each division had its own power unit, the one of 80 h.p., the other of 25 h.p. These were supplementary to the water power for which the site had originally been chosen. A large proportion of the machinery, especially that used for the gunstocks, was brought from the United States, and the whole factory was the result of a careful study of the methods used in the national musket factories in Belgium and America.[1]

(b) *Manufacturing Programme.*

At the outbreak of the European War, the Royal Small Arms Factory was chiefly engaged in the manufacture of S.M.L.E. rifles, but it was also responsible for producing certain accessories such as bayonets, scabbards, cavalry swords and chargers; for the resighting of rifles for Mark VII. ammunition; the supply of spares for the Chief Ordnance Officer at Weedon; repairs to rifles and to certain machine guns. Experimental work was undertaken to a certain extent and, during the war, some special work, such as the determination of the amount of phosphorus and sulphur permissible in certain classes of steel.[2]

Since 1912 all requirements for rifles for Home Service had been met from Enfield, and the average annual output of the newest type of rifle for current equipment was 25,279[3] with a certain number for replacement of stock. The theoretical output on a two-shift capacity was 4,200 rifles a week,[4] and the actual output immediately prior to to the war was 1,000 new and about 1,000 repaired rifles weekly, while of accessories 600 bayonets, 700 scabbards and 50 cavalry swords were made per week.[5]

Output of all arms increased rapidly on the declaration of war. By September, 1915, 6,000 complete rifles were turned out weekly, repairs averaged about 6,000 a week, and a good deal of work was done in the provision of locks and spare parts for machine guns. In addition, up to December, 1915, a total of 51 Maxim guns were made. The manufacture of accessories had similarly increased; for instance, in June, 1915, scabbards were produced at the rate of 4,900 per week, but the supply of rifles to be resighted had come to an end.[6]

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[1] *Evidence and Report of Select Committee on Small Arms,* 1854; J. Tuff, *Historical Notices of Enfield* (1858).
[2] D.D.G.E./E.M. 4/325.
[3] HIST. REC./H/170/5.
[4] Sec./RS/135B1.
[5] O.F./Gen./039.
[6] HIST. REC./R/1122.1/4; O.F./Gen./039; D.D.G.E./E.M.1/41.

With the development of the "peddled scheme"[1] of rifle manufacture in the autumn of 1915 and the first few months of 1916, the manufacture of bayonets, which had reached 6,000 weekly by October, 1915, was entirely entrusted to the trade and the capacity so released was devoted to the production of rifle bodies. For the assembling of rifles made from these and other bodies manufactured outside the factory, and from components turned out by the trade, a special shop was erected at Enfield. In January, 1916, the scope of the scheme was enlarged by the formation at Enfield of a rifle component pool into which were put all the surplus components made by the rifle factories, all parts produced by component manufacturers and the output of bodies for peddled rifles.

After 1916[2] the demand for cavalry swords and chargers fell off. Output had reached 900 and 500,000 per week respectively, but by September, 1917, this work, except for repairs, had entirely ceased. At the end of 1917 it appeared advisable to reduce the output of rifles as demands were being more than met, and early in 1918 it was arranged to stop the manufacture of peddled rifles; but owing to the demand for machine gun parts, which could best be produced at Enfield, it was decided to continue the peddled scheme at its maximum output and by reducing the output of Enfield-made rifles to devote the extra capacity to the manufacture of machine gun parts in addition to the repair work on Lewis guns which the Superintendent had recently undertaken.[3] This programme was interrupted by the increase in rifle requirements put forward in April 1918,[4] and the factory again worked up practically to its maximum output at the expense of the machine gun scheme. During the autumn of 1918 the output was again reduced and decreasing rapidly after the signing of the Armistice was, by January, 1919 about 36 per cent. of the October, 1918 average. In 1919 it was decided to stop the production of new weapons, to retain sufficient material to assemble 100,000 rifles[5] and to employ the staff on repair work only.

(c) *Administration.*

For purposes of administration, the Royal Small Arms Factory and the Royal Gunpowder Factory at Waltham were, for the first two years of the war, united under the charge of one Superintendent, Colonel F. T. Fisher, who was directly responsible when war broke out to the Master-General of the Ordnance, except for questions relating to finance and accounts, which were referred to the Chief Superintendent of Ordnance Factories. The Assistant Superintendent at Enfield was Major S. C. Halse, and there were in addition to the technical staff a Building Works Department and a Common Services Branch which was shared with the Royal Gunpowder Factory. The central office was at Enfield and the factory was also the headquarters of the Chief Inspector of Small Arms.

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[1] Vol. XI, Part IV, Chaps. II, III, V.
[2] Vol. XI, Part IV, Chap. III.
[3] D.D.G.E./E.M.4/330.
[4] D.D.G.E./E.M.4/406.
[5] 77/Gen. No./4785.

On the formation of the Ministry of Munitions, Colonel Fisher and Major Halse, while acting as technical advisers to the Ministry, continued to report to the Master-General of the Ordnance,[1] but in August, 1915, when the Ordnance Factories were taken over by the Ministry, the administration of Enfield was dealt with by a branch known as C.M.7. in the Department of the Director-General of Munitions Supply.

In January 1916 the two factories were divided for the purposes of departmental control[2] and were attached for administrative purposes to the units of the Ministry concerned with the stores which they respectively manufactured, Enfield being dealt with by a branch known as E.M.4 in the Department of the Director-General of Ordnance Supplies. From the point of view of finance and accounts, the Ordnance Factories continued to form a single concern and the central office at Enfield was retained. At the same time Colonel Halse, who was also engaged on part time duty at the headquarters of the Ministry, was appointed Deputy Superintendent with full responsibility to Colonel Fisher for the manufacturing output of the factory.[3] In May, 1917, Colonel Halse gave up his duties at Enfield,[4] and in December, 1917, on the resignation of Colonel Fisher, Enfield was separated from Waltham, the common services staff were divided and Colonel C. I. Newton appointed as Superintendent of Enfield.[5]

During the war several variations in the normal procedure were allowed. For instance, in certain ways the Superintendent was given greater powers. In normal times requisitions for machinery were dealt with from headquarters, but soon after the outbreak of war the Superintendent was permitted to purchase urgently needed machines "over the counter."[6] Again shortly after the beginning of hostilities he was ordered by the Master-General of the Ordnance to undertake the provision of timber for trade-made rifles as well as for the factory's output.[7]

Normally, expenditure for the ensuing year was approved beforehand, and an allotment made to the Superintendent of a sum sufficient to cover maintenance and minor unforeseen expenses. During the war the rapid increase in the cost of labour and material and the expansion of the factory made accurate forecasting a matter of impossibility and additional allotments in the course of the year were frequently required.[8] No new services above £200 in cost were put in hand without special authority. Building services were usually opened to competitive tender, but in many instances the factory workmen were employed without recourse to the open market.

(d) *Factory Expansion.*

The position of the Royal Small Arms Factory on the way to the coast, in a flat country liable to heavy floods with but little accommodation for other than the permanent staff, and practically no building

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[1] D.D.G.E./E.M.1/40.
[2] Office Instruction No. 87..
[3] D.G.O.S./Enf./17.
[4] Departmental Office Notice, No. 36.
[5] C.R./DGSG/2512.
[6] 77/Gen. No./4757.
[7] OF/Gen./039.
[8] D.D.G.E./E.M.4/94; O.F./Bldgs/55.

land available, with other large factories in the neighbourhood, and at a distance from the supply of coal, iron and steel, was as bad a site as could well be conceived for the production of more than half the available rifle supply; although it had originally been chosen in view of its waterways. Nevertheless the difficulties of rifle manufacture were such that it was impracticable to start up new factories,[1] and as the possibilities of extending the trade rifle factories were limited, it became necessary, when the contracts placed in America failed to produce the deliveries required, to depend for the increased supply largely upon extensions made to the Enfield shops. Moreover, the success of the peddled scheme depended primarily on the soundness and reliability of the organisation which was to test and assemble the parts. This need Enfield was best able to supply.

Sanction for the extension of the plant to a capacity of 5,750 rifles a week was given in October, 1914[2] but subsequent proposals to double or largely extend the place were rejected on account of the difficulties involved. From time to time, however, additional machinery was acquired as for instance from the Standard Small Arms Company in 1916,[3] and in addition, a number of shop extensions were made, especially in connection with the development of the peddled scheme. By June 1917 in addition to the extension of the bayonet plant[4] and the erection of a new assembling shop, the Superintendent reported progress with a new barrel mill, a new stocking shop, a new automatic screw shop, a repair shop, browning shop, machine gun shop, oil store, stores for gun stocks and new accommodation for the clerical staff. The supply of gas and electricity was supplemented by power from local bodies.[5]

The introduction of female labour necessitated provision of special facilities such as a canteen and rest and recreation rooms. Ingress and egress were rendered somewhat easier by new bridges over the water. The handling of so much material presented special difficulties and at times the congestion was serious. Trucks were left for some days under load.[6]

To expedite matters, various improvements were made, such as the extension of a railway siding into the factory, a development which proved of inestimable value,[7] and the laying of a new road for heavy cart traffic.[8] Considerable use was made of the waterways, and a helpful remedy was found in the employment of petrol lorries and the diversion of stores intended exclusively for the Royal Gunpowder Factory to another station.[9]

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[1] *See* Vol. XI, Part IV, Chap. V.
[2] OF/Gen./039; 77/Gen. No./4757.
[3] *See* Vol. XI, Part IV, Chap. II.
[4] Converted in 1916 to a body-making shop. *See* above, p. 30.
[5] D.G.O.S./Enf/23; D.G.I.M./Bldgs./213; D.D.G.E./E.M.4/93. For other extensions, *see* D.D.G.E./E.M. 4/247, 115, 100; O.F./Bldgs/038; Hist. Rec./R/1122.1/3.
[6] D.D.G.E./E.M.4/61.
[7] Hist. Rec./R/1122.1/3; D.D.G.E./E.M. 4/114.
[8] Approved 13.3.16. D.D.G.E./E.M. 4/57.
[9] Hist. Rec./R/1420/21; D.D.G.E./E.M. 4/2.

(e) *Labour.*

The labour difficulties prevalent everywhere were at Enfield accentuated by the unsuitable location of the factory. For instance, the proposal in March, 1915, to double the output of the factory was abandoned largely because the labour available in the district was almost used up and it was impracticable to bring in a large amount of outside labour when there was no accommodation for billeting workmen, nor any chance of a successful housing scheme.[1] Nevertheless, there was a very large gradual increase in staff and long distances had to be traversed. A limited attempt to minimise the ill effects of fatigue was made in the provision of a hostel for women,[2] and there were rest rooms and clubs in the precincts of the factory. Various concessions in the rules were also made for the benefit of workers. A fair number of boys were employed, but by March, 1915, the supply was poor owing to the high wages offered in local factories. In May, 1916, they were 10 per cent. of the total strength and in May, 1918, 6 per cent.[3] In the early months of 1916, dilution by women was thoroughly discussed and in April 51 women were engaged on unskilled work. The constantly increasing demand for arms severely militated against the substitution of women for men as a matter of pure dilution and the highly specialised nature of much of the work limited their number. Nevertheless, by May, 1918, there was a certain number in all departments[4] and as a result of an investigation by the dilution officer, the training of women on more specialised work, not hitherto attempted by them was projected.[5] The employment of volunteers also tended to lessen the problem. In September, 1915, there was a considerable number at work on Sundays and at the end of October, 1918, there were 265 in the factory.[6] The quality of labour obtainable, however, had a somewhat adverse effect on the work and in June, 1917, the Superintendent complained of the reduced output obtained from the older men, and of the large number of men who were found to be physically incapable of the work,[7] while the poor quality of some of the peddled components necessitated the employment of additional labour.

On March 3, 1916, the Royal Small Arms Factory was declared a controlled establishment. The chief result of this step in respect of the factory was that trade union customs which tended to restrict production were suspended and that the breaking of shop rules became an offence under the Act.[8]

The years 1917 and 1918 proved specially difficult. The abolition of the leaving certificate resulted in the loss of 132 skilled men and in the spring of 1918 the position became really serious. Many men were lost to other factories where special inducements were offered, and

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[1] 94/R/14.
[2] Approved 11.10.16; D.D.G.E./E.M. 4/117.
[3] 94/R/14; D.D.G.E./E.M. 4/118; C.E. 1949/3.
[4] The percentage of the total staff was 15·3 per cent.
[5] C.E. 1949/12, 3; D.D.G.E./E.M. 4/42, 58; D.G.O.S./Enf./23.
[6] D.D.G.E./E.M. 4/554.
[7] D.G.O.S./Enf./23.
[8] D.D.G.E./E.M. 4/46.

by May, 1918, urgent machine gun repairs had to be reduced for lack of labour.[1] Gaugemakers especially were difficult to obtain and as Enfield supplied all standards and check guns for the manufacture of rifles to various firms throughout the country and in India, there was cause for real anxiety. Semi-skilled labour was indeed obtained from the training schools, but the period and quality of training were not sufficient to produce the highly skilled workmen who were so essential in successful rifle production. The Superintendent further suffered loss of expert staff such as the transfer of Colonel Halse to the headquarters of the Mininstry, and the loan of special staff to the rifle factories in the United States.

The following numbers give some indication of the increase in staff during the war. In July, 1914, about 1,800 men and boys were employed. By October the number was 4,210 increasing to 4,848 in December, 1914. In April, 1916, the total number including 51 women was 7,754 and in October, 1917, there were 7,707 men, 863 boys, 1,438 women and 106 girls. At the end of April, 1918, there were 9,554 persons employed of whom 7,300 were men, 777 boys, 1,404 women and 73 girls.[2] Office staff, although it increased considerably, formed only a small percentage of the total numbers employed. In 1918 the salary and wages bill including war bonuses approximated to £3,000,000.[3] After the signing of the Armistice the staff was rapidly reduced and it was arranged that by March 31, 1919, the men were to be at the peace strength of 1,800 and all women were to be discharged by January, 1919.[4]

(f) *Output.*

Demands were issued by means of extracts for 100,000 rifles at a time; the stores branch at the factory ordering material as soon as the extract was received and issuing appropriate quantities to the various shops.

In addition to material required for the supply of factory-made rifles, the Superintendent purchased and issued all wood used by trade rifle and component manufacturers. For this purpose walnut was the only satisfactory wood, and when, soon after the outbreak of war, European supplies failed and the small stocks in Great Britain were exhausted, America became the only source of supply. The regular shipment of sufficient quantities was a constant anxiety. Moreover, as a large amount of the American timber was purchased in plank, it was necessary to instal saw mills and to train a special staff of tracers and viewers.[5] To minimise risks from fire the wood was stored in specially constructed buildings and where possible, distributed in local maltings hired for the purpose, but it was very difficult to secure a large reserve.[6]

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[1] C.E. 1949/3; D.D.G.E./E.M. 4/437.

[2] D.G.O.S./Enf./23; C.E. 1949/13.

[3] Higher Staff, £6,544 and £209 war bonus; Factory Staff, £2,332,501 plus £719,715 war bonus; Clerks £27,841 and £7,882 war bonus (D.D.G.E./E.M.4/353).

[4] D.D.G.E./E.M. 4/631.

[5] O.F./Gen./039.

[6] D.D.G.E./E.M. 4/126; D.G.O.S./Enf./23.

The rifle making factories purchased their own steel, but at the outset of the peddled scheme, the Superintendent, to help contractors who desired it, supplied steel from Enfield, at first free, but later on repayment. By 1918 all steel for the rifle component pool contractors was issued by the Superintendent.[1]

The earliest deliveries under the peddled scheme did not begin until July 1916, but when the scheme was in full working order, it was estimated that 8,500 complete rifles were made weekly in the factory from factory-produced components, and the remainder were regarded as peddled rifles. Of these up to 10,000 rifles weekly were turned out with but little help from the component pool, but all in excess of this number were almost entirely made from peddled components. During the period of the war the output of the factory was as follows :—[2]

	1914. Aug. to Dec.	1915.	1916.	1917.	1918.	Total.
Rifles, S.M.L.E. ..	63,107	253,545	413,424	618,073	659,423	2,007,572
Machine Guns, Maxim ..	13	38	307	308	—	666

In addition to complete machine guns, 130,326 barrels[3] for guns of various types were made and 6,566 locks. Other parts and accessories for machine guns were of an exceedingly miscellaneous nature.[4]

In all, they amounted to over 1,000,000 articles, of which 506,000 were ammunition belts of different kinds, 172,000 tin boxes, and 119,000 mirror reflectors. Most of these were intended for Maxim guns, but a good deal of work for Vickers guns was done. Repairs were undertaken on 600 Maxim, 6,900 Vickers and 260 Lewis guns. In addition to complete rifles made from factory or peddled stock, approximately 425,000 bayonets, 52,000 cavalry swords, and 1,500,000 scabbards were manufactured. Rifle parts and accessories were also produced in great diversity, making a total of about 65,000,000 of which 5,500,000 were pull-throughs, 356,000 wooden components, 2,200,000 oil bottles, 55,000,000 charges, and 5,000 barrels.[5] Rifles were repaired, to the

[1] D.D.G.E./E.M. 3/949.

[2] HIST. REC./H/1122.1/4.

[3] 6,000 Mark IX Lewis; 11,539 Maxim (including conversions); 112,787 Vickers.

[4] They included, for instance, apparatus for firing miniature ammunition, water bags, feed blocks, brushes, extractors, crank handles, hyposcopes, filling belt machines, muzzle attachment for ball firing, firing pins, plugs of different kinds, muzzle protectors, cleaning rods, connecting rods, shoulder pieces, fore and tangent sights, muzzle attachment cleaners, triggers, steam tubes, tumblers, water vessels.

[5] The various rifle parts and accessories produced were butt plates, screw plates, clearing plugs, back and fore sight protectors, cleaning rods, rifle attach ments for trench howitzers, actions of artillery carbines, aim correctors, stock butt anvils, bits, fore sight blades, bodies, breech and locking bolts, wire breakers, tube aiming cleaners, cocking pieces, pull through cords, fore-end floats, gauges, sword bayonet grips, breech bolt heads, armourers' horses, action implements, lances, backsight leaves, linings, lockets, magazine cases, magazines, mandrils.

number of about 1,400,000, and repairs were also effected to cavalry swords, scabbards, bayonets, pistols and lances.[1]

The cost of rifle production varied but little. In June 1916 the cost per rifle was estimated at £3 5s.[2] and in June 1918, including depreciation and overhead charges, was £3 18s. 5d.[3]

The factory was fortunate in suffering but little damage from fire and air attacks. At no time was there any loss of output from fire, and although in the autumn of 1917 a serious fire broke out, the damage was confined to the women's welfare quarters.[4]

A number of air raids occurred in the district, but again no structural damage was done. The screening of the lights was a matter of considerable difficulty, and a special inspection by airship proved that the factory could be easily located. In the darkened paths and roads outside accidents not infrequently occurred, especially in the water ways.[5]

The effect of raids on output was, in comparison with the number of attacks, small. For instance, of eleven raids in the latter part of 1917 involving a total loss of about eighteen hours, nine had no effect on output, but as a result of the remaining two, a total of 2,600 rifles and a corresponding number of components were lost.[6]

In spite of the special difficulties of manufacture at Enfield the factory proved its capacity for effective development and to the soundness of its organisation the peddled scheme owed practically all its success. It had the inestimable advantage of a highly trained nucleus staff, and the quality of the work was particularly high. The resulting product was a thoroughly sound and highly finished weapon which fulfilled its object by retaining the absolute confidence of the soldier on the field.

IV. The Royal Gunpowder Factory, Waltham Abbey.[7]

The Royal Gunpowder Factory, Waltham Abbey, is of very great antiquity, the earliest known record of Waltham Abbey Powder Mills dating back to the reign of Elizabeth. In 1787, the factory was purchased by the Government, and since then it has always been known as the Royal Gunpowder Factory. In 1872, the production of guncotton on a manufacturing scale was commenced, and in 1885, 100 acres of land, known as Quinton Hill, were purchased and a new guncotton factory erected which started work in 1890. In 1891, the production of cordite commenced, the necessary nitroglycerine factory and buildings for making cordite having been erected on Quinton Hill after the recommendation made in 1890 that the smokeless powder known as

[1] The total numbers of these arms repaired were 1,535,034.
[2] 94/R/392. Material 11s. 8d.; Wages, £2 2s. 8d. Indirect expenses 10s. 8d.
[3] D.D.G.E./E.M. 3/1083.
[4] D.D.G.E./E.M. 4/221, 280.
[5] O.F./Bldgs./023.
[6] D.D.G.E./E.M. 4/237.
[7] Hist. Rec./H/1122.12/1, 2; Hist. Rec./R/1122.12/2; 1122.1/9; 1122.7/24, 26; 95/C/314.

cordite should be used for the British service. In 1901, the introduction of cordite M.D. necessitated considerable extensions. The manufacture of tetryl was begun in 1910 on a very small scale.

At the outbreak of the war, Waltham Abbey was the only government factory making cordite, gunpowder, guncotton and tetryl. It was controlled on behalf of both services by the War Department through the administration of the Superintendent of Waltham Abbey and Enfield. In August, 1915, it was taken over by the Ministry of Munitions, and was administered by the Director General of Munitions Supply until transferred in January, 1916, to the Director General of Explosives Supply. It was, thereafter, directly controlled by the Propellants Branch of the Explosives Supply Department and was under the management of a Superintendent. For some time after its transfer to the Ministry of Munitions a part of its output was still allocated to the Admiralty, but in October, 1916, the Admiralty, having accumulated large stocks of cordite, agreed to the transfer of the whole of the Royal Gunpowder Factory cordite output to the Ministry.

The nature of the site, which consisted of a long strip of land, limited the expansion of the factory, and prevented the lay-out of new plant from being arranged along the simplest and most economical lines.

As regards cordite, the approximate maximum pre-war capacity of the factory was 70 tons a week. By August, 1915, its output had been increased to 140 tons of cordite M.D. per week. After its transfer to the Ministry of Munitions the capacity of the factory was further increased to 250 tons of cordite R.D.B., or 200 tons of cordite M.D. per week. The manufacture of R.D.B. flake cordite was introduced towards the close of 1917.

The actual output of gunpowder in the four months preceding the outbreak of the war averaged 4½ tons a week. In the next four months this average rose to 8½ tons. The plant then existing proved adequate to meet the demands made on it.

Prior to the war tetryl was made on little more than a laboratory scale. Plant extensions were, however, made in the early days of the war, and in September, 1915, the output was rather over 5,000 lbs. per week. By January, 1916, increased plant to reach an output of 25,000 lbs. per week had been installed. Fires unfortunately destroyed two drying stoves in July, 1916, the new acetone purification house on 22 February, 1917, and the purification and corning house on 15 February, 1918.

During 1917, the water purification process for producing Grade II tetryl was placed on a satisfactory basis and in 1918 a temporary plant was installed for the production of Grade IA tetryl by the nitric acid purification process and a permanent plant capable of dealing with 20,000 lbs. per week was nearing completion when the Armistice was signed.

The total factory output during the whole period of the war was 31,716 tons of cordite, 1,629 tons of gunpowder, 10 tons of gunpowder pellets, 1,632 tons of tetryl, 2,424 tons of guncotton and 252 tons of fuse powder.

At the outbreak of the war 918 male workers were employed. By March, 1916, the number had risen to 3,800. In April, 1916, dilution with female labour was begun and by May, 1917, the employees numbered 2,637 men, 478 boys, 1,832 women, and 314 girls, *i.e.* a total of 5,261. The maximum number employed was in March, 1918, the figures then being 2,691 men, 431 boys, 2,277 women, and 331 girls, giving a total of 5,730. The original employees were practically all local residents. It proved possible to draw a sufficiency of labour, both male and female, from the surrounding districts and the North of London. On the signing of the Armistice steps were taken to reduce output, to discharge all the women workers, and to reduce the number of men and boys to approximately pre-war number.

V. The Royal Aircraft Establishment, Farnborough.

The Royal Aircraft Factory, known since 1918 as the Royal Aircraft Establishment, was founded as a balloon factory in 1905. In 1911 it became the Army Aircraft Factory, and in 1912 the Royal Aircraft Factory.[1] Until the end of 1913 airships and aeroplanes were designed and built there. All airships were transferred to the navy at the end of 1913, and the Royal Aircraft Factory was from that time devoted to research and invention in heavier than air craft. The Royal Aircraft Factory nominally existed as a technical department for both services, but the Admiralty made comparatively little use of its resources and developed an independent technical branch. Thus, on the outbreak of war, the establishment at Farnborough was entirely under the control of the Director-General of Military Aeronautics.

For the first two years of the war much pioneer work in design both of aeroplanes and aero-engines was carried out at the factory. A certain amount of manufacture was also done in connection with experimental machines and in emergency cases to supplement the failures of contractors. Engine repairs and the provision of spares, both for engines and aeroplanes, were important branches of the work, and between March, 1915, and November, 1918, 2,310 engines were repaired. A great deal of research was done on materials used in manufacture, especially fabric and dope, for the investigation of which a chemical laboratory existed. One of the particular features of the factory was the full-scale experimental and research work carried out there. It was found towards the end of 1915 that the amount of design work carried on at the factory tended to prevent healthy competition by private firms, and was the cause of jealousy on the part of contractors, and from this time it was found desirable to reduce the original design work done at Farnborough and to give further encouragement to the designs of private firms.

The factory was administered under the Director of Military Aeronautics by a superintendent. An enquiry was held in May, 1916,

[1] *Final Report of Committee on Administration and Command of Royal Flying Corps.*

on the organisation of the factory, and it was suggested by the committee that a Board of Management should be formed consisting of a Chairman or Director, a Superintendent of Designs and a Superintendent of Manufacture, who should be preferably civilians, with a Military Adviser without distinctive executive duties. The Air Board did not agree with this recommendation, believing that a Board of Management would not be well adapted to the exigencies of a military organisation. They recommended a single superintendent with two subordinate officers who should be heads of the design and production branches respectively.

The suggestion of the Committee that the capacity of the factory should be directed to an increase of the current manufacture of aeroplanes and engines raised a difficult question. From a financial point of view such an extension was desirable, as the costs of an experimental establishment such as Farnborough were bound to be high. On the other hand, the limited amount of production already carried out at the factory had aroused jealousy on the part of private manufacturers, and the Air Board recommended the development of the experimental side of the work, rather than the production side.

A reconstruction of the management of the factory, on the lines recommended by the Air Board, took place in September, 1916, when Mr., afterwards Sir Henry, Fowler, became Superintendent.

The position of the factory under the new conditions, which resulted from the transference of supply to the Ministry of Munitions in March, 1917, was the subject of much debate.[1] The experimental side of the establishment seemed to be the province of the technical department of the Air Board, while the manufacturing side clearly belonged to the supply department. It was finally arranged to place the factory under the supply department, its Superintendent being responsible to the Controller of Aeronautical Supplies. It was treated like any other contractor and could submit designs for the approval of the technical department. It was still used mainly as an experimental factory, and its work was not greatly modified under the new conditions.[2] Its design branch provided the supply department with the knowledge necessary for the production of such highly technical stores as aircraft and aero-engines, but its facilities were available for any experiments desired by the technical department.[3] By the middle of 1917, the factory was re-organised. At the beginning of 1918, Mr. Sydney Smith was appointed as Superintendent in succession to Sir Henry Fowler, who had been transferred to the Air Board as Assistant Director-General of Aircraft Production. About the same time the technical department was transferred to the Department of Aircraft Production, thus bringing the Royal Aircraft Factory under the sole control of the Ministry of Munitions. The establishment was handed over to the Air Ministry on 1st January, 1920.

In its general outlines, the organisation of Farnborough resembled that of Woolwich Arsenal. On the outbreak of war, the staff of trained

[1] A.C. 137.
[2] HIST. REC./R/1960/1.
[3] C.R. 4402.

engineers at Farnborough served both as a supply for the required supervising and inspecting staff and also as a nucleus for training new men for the work, while the manufacturing capacity at Farnborough served to carry on production over the period while the industry was being built up. For the first few months of the war final inspection and flight test of all machines were carried out at Farnborough, but this led to delay and congestion as output increased. At the beginning of 1915 this work had to be decentralised and aerodromes and inspecting staff were provided at other centres throughout the country. On the outbreak of war a large proportion of the spares supply for the Royal Flying Corps was still being dealt with by the factory both as regards provision and storage. The Aeronautical Ordnance Department had, however, already been established at Pinehurst, and in August, 1914, it took over from the factory the Royal Flying Corps stores work, with the exception of certain special items such as instruments.

The system of issue of drawings differed at Farnborough and Woolwich. At Woolwich the Inspection Department issued all drawings to contractors, but at Farnborough, owing to the fact that for the first year of the war the majority of machines built by contractors were of factory design, drawings were issued by the Superintendent of the Royal Aircraft Factory direct to contractors. The fact that frequent alterations in drawings were necessary after their issue gave ground for criticism of the factory, and from the beginning of 1916 every effort was made to reduce the amount of direct communication between the factory and contractors. The establishment of a technical branch at headquarters early in 1916 relieved the factory of all duties in connection with the issue of drawings and specifications.

It was possible to carry out dilution of labour to a large extent at Farnborough: female labour had always been used in the dope and fabric shops, and during the war dilution took place in the other manufacturing departments, and also, where possible, in the technical and administrative departments.

The strength of the Royal Aircraft Factory on 26th March, 1916, was 4,222 and the wages bill (excluding the salaries of eight chief officials) for the week ending 26th March, 1916, totalled £10,409.

The costing system at the factory in the early days was comparatively simple, but a very elaborate system was introduced by the Ministry of Munitions. After the factory came under the Air Ministry the system was completely revised and simplified. Very detailed records of the materials used in the manufacture of each part of an aeroplane, and of the course through which the components passed in the various stages from the raw material to the finished article, were introduced in the early days of the factory to ensure that every detail of an experimental machine might be traced back to the particular batch of material from which it was made.

The following tables show the output of aeroplanes from the factory during the last four years of the war, and the number of engines repaired during the same period.

TABLE IV.

Issues from the Royal Aircraft Establishment, Farnborough.

(*a*) AEROPLANES MANUFACTURED, JANUARY, 1915, TO NOVEMBER, 1918.

Type.	1915.	1916.	1917.	1918.	Total.
R.E. 5	2	—	—	—	2
R.E. 8	—	39	6	—	45
F.E. 2A	12	—	—	—	12
F.E. 2B	11	36	—	—	47
F.E. 2C	—	2	—	—	2
F.E. 2D	—	74	11	—	85
F.E. 4	—	2	—	—	2
F.E. 8	2	—	—	—	2
F.E. 9	—	—	3	—	3
S.E. 4A	4	—	—	—	4
S.E. 5	—	2	132	—	134
S.E. 5A	—	—	—	102	102
N.E. 1	—	—	4	2	6
C.E. 1	—	—	1	1	2
A.E. 3	—	—	—	3	3
Handley Page	—	—	—	24	24
Vickers Bomber	—	—	—	1	1
Special	—	—	6	—	6
Totals	31	155	163	133	482

(*b*) ENGINES REPAIRED FOR ROYAL AIR FORCE, MARCH, 1915, TO NOVEMBER, 1918.

Type.	1915.	1916.	1917.	1918.	Total.
Renault 60 h.p...	1	—	—	—	1
„ 70 h.p...	87	41	—	—	128
„ 75 h.p...	—	6	—	—	6
„ 80 h.p...	—	3	—	—	3
Gnome 80 h.p...	112	83	—	—	195
Mono 100 h.p...	13	6	—	—	19
Le Rhone 100 h.p.	1	—	—	—	1
Clerget 80 h.p...	—	3	—	—	3
Green 100 h.p...	—	1	—	—	1
Beardmore	—	60	—	—	60
Rolls Royce	—	51	60	—	111
Sunbeam	—	—	6	—	6
Hispano	—	—	22	937	959
R.A.F. 1A	25	276	243	—	544
R.A.F. 3A	—	—	2	—	2
R.A.F. 4	—	—	174	—	174
R.A.F. 4A	—	29	89	12	130
R.A.F. 5	—	—	1	—	1
Totals	239	559	597	949	2,344

CHAPTER II.

HIS MAJESTY'S EXPLOSIVES FACTORIES.[1]

I.—Introduction.

(a) *Development of the National Factories for Explosives Production.*

The first factories erected for explosives manufacture were the earliest of the numerous state factories which were established for the purposes of the war. In October, 1914, there arose an unprecedentedly large demand for T.N.T. The manufacture of high explosives had never been undertaken by the Ordnance Factories. There was practically no trade capacity for manufacture of military T.N.T., and the stocks of the commercial explosive which were available needed treatment to bring them up to service standards. As soon as power to requisition the entire output of factories had been taken under the Defence of the Realm (Consolidation) Act, in November, 1914, arrangements were made by the War Department to acquire and operate works at Rainham which were suitable for purifying the commercial product. The manufacture of T.N.T. presented grave technical difficulties and the demand for it was in practice limited only by the amount of the raw material, toluol, which was available. Economical methods of manufacture were accordingly essential and the Committee on High Explosives, under the presidency of Lord Moulton, favoured the erection of a national factory for the purpose, in order to ensure control over the layout, to facilitate development in accordance with the information as to manufacturing processes which was daily increasing and to make the best use of the limited number of technical experts who had special knowledge of this subject. Mr. K. B. Quinan was summoned from South Africa, towards the end of December, 1914, to construct the first national T.N.T. factory at Oldbury, and the work of erection began in the following month. The factory was to be operated under an agency agreement by a well-known firm of acid-makers, Messrs. Chance and Hunt, and an essential part of the project was the transfer from Rotterdam to Portishead of the Asiatic Petroleum Company's plant for distilling toluol from Borneo Petroleum. The Asiatic Petroleum Company undertook to operate this distillery for the State under an agency agreement and also to erect at Oldbury plant for nitrating the toluol up to M.N.T., the basic material for the national T.N.T. factory, of which the M.N.T. plant subsequently became an integral part.

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[1] See Vol. X, Part IV, for the authorities for this account, and for the relations of the national factories to the general arrangements for explosive supply.

Meantime, naval authorities had decided in favour of the erection of a Royal Naval Cordite Factory as preferable to the advance of large sums for the extension of plant by the chief explosive makers, who were unwilling that subsidised plant should revert to the State at the end of the war. The scheme for this factory, which was ultimately erected at Holton Heath, near Poole, was authorised by the First Lord of the Admiralty early in February, 1915. It was not, however, considered that the guncotton section could be in operation at a sufficiently early date, and Lord Moulton undertook to expedite guncotton manufacture by converting derelict works at Queen's Ferry into a government factory for this purpose. The project was first mooted at the end of February, but the site was not available until the middle of May, and at the end of that month the output anticipated from the factory was earmarked for military use.

From May, 1915, till the end of that year, the state factories for explosive manufacture developed with great rapidity. It was not considered necessary in May, 1915, to make further extensions to the capacity for making high explosives in order to balance the schemes of the Munitions of War Committee for increased shell production; but a project for manufacturing 2,000 tons of some substitute propulsive monthly was set on foot by that committee. Lord Moulton undertook to ensure this supply by erecting a single large, national factory. Preparations for the new factory were continued throughout the month of June, and, on 26 June, shortly after his appointment as Minister of Munitions, Mr. Lloyd George gave Lord Moulton formal authority to proceed with its erection. Thus originated the enormous state factory at Gretna for the manufacture of cordite R.D.B., with the entirely new township created in the open country for the housing of the operatives.

The extended gun ammunition programmes formulated in the summer of 1915 gave rise to large extensions to the national plant for explosive manufacture. The capacity of Gretna was increased. The Oldbury and Portishead factories for T.N.T., M.N.T. and toluol were duplicated at Queen's Ferry, Sandycroft and Barrow. Contractors' works for making T.N.T. at Penrhyn Deudraeth, which had been destroyed by explosion, were re-erected as a government factory. Land was taken at Watford for a national ammonal factory to supplement the trade capacity for this explosive, which had already been extended to the utmost to provide against the increasing output of trench mortar bombs.

Throughout the year, the practice continued of erecting new national plant for making explosives or their materials. A serious shortage of tetryl in the autumn was met by extending the plant at the Royal Gunpowder factory and also by adding a tetryl section to the Queen's Ferry factory. Manufacture of synthetic phenol was undertaken in a state factory erected at Ellesmere Port in October, 1915, and erection of a government refinery for commercial toluol was begun at Trafford Park in that same month. Ammonium perchlorate production was arranged at a national factory at Langwith

in the following November. Grillo plant for oleum manufacture was added to the Queen's Ferry factory in December, 1915.

In addition to establishing new works, the Explosives Supply Department of the Ministry of Munitions also took over certain contractors' works for various reasons. The complexity of the negotiations with Nobel's Explosives Company for erecting plant at Pembrey to manufacture T.N.T., cordite and ballistite on behalf of the Navy as well as the Army led to an agreement in October, 1915, for the amalgamation of the contracts relating to this factory and for its operation by the firm as an agency factory under the Ministry as from January, 1917, onwards. To improve output, two T.N.T. factories at Hackney Wick and Litherland and a plenol factory at Sutton Oak were nationalised in July, 1915, March and May, 1916, respectively. A gun cotton factory, leased from the Belgian Government by the Colnbrook Chemicals and Explosives Company Limited was nationalised in June, 1916, on account of the unsatisfactory position of its output and finances.

In April, 1916, land was taken at Craigleith, outside Edinburgh, for the erection of a new national T.N.T. factory. It was to supersede works which had been successfully operated by members of the Edinburgh University and others trading as the Lothian Chemical Company, but was dangerously situated in a congested neighbourhood. No further factories were erected for T.N.T. production, but by the summer of 1916 all trade capacity for picric acid manufacture had been exhausted and a project for the national manufacture of this explosive was set on foot, chiefly with a view to utilising surplus quantities of phenol. A site for a large picric acid factory was found at Avonmouth, and the scheme included the erection of a large oleum plant in connection with neighbouring plant for roasting zinc ore. Later in the year three new state factories were projected for picric acid manufacture. These were situated at Bradley, Greetland and Lytham, and were operated by agents, whereas the Avonmouth factory was under the direct control of the Department.

At the end of 1916 plans were also made to construct at Henbury and Irvine two national factories to produce at home nitrocellulose powder, an American explosive which had previously been obtained from overseas only. This project was based upon existing uncertainty as to the maintenance of supplies from the United States. With the entry of the American Government into the war, and the increased stringency in the shipping position, the scheme was greatly reduced. The project for the Henbury factory was eventually abandoned in May, 1917. The construction of the factory at Irvine was continued slowly. For similar reasons the picric acid plant at Avonmouth was restricted to two-thirds of the original scheme, and owing to the gradual abandonment of picric acid, the plant was never used for this purpose.

The growing stringency of the tonnage position led to the development of the home manufacture of ammonium nitrate, mainly by contractors working under cost plus percentage agreements, but also at a national factory which was erected at Swindon early in 1917.

State manufacture of calcium nitrate had been undertaken during 1916 at H.M. Factory, Victoria, which was at first operated by Messrs. Brunner, Mond in conjunction with trade factories for ammonium nitrate production in the Northwich district. A plan to erect a second national factory for calcium chloride on land adjacent to the Victoria Works was authorised in October, 1916, and abandoned towards the end of December, when the development of a simpler process had facilitated the erection of the self-contained ammonium nitrate factory at Swindon.

The erection of national plant for producing the complete explosive was brought to an end with the abandonment of the picric acid and nitrocellulose powder factories at Avonmouth and Henbury. Some new projects were, however, set on foot for the State manufacture of materials with a view to increasing home production. Several additions were planned in 1917 to the wood distillation factories which had already been established under Government control for the manufacture of acetone and other products. The cotton waste mills originally managed by the British and Foreign Supply Association were nationalised in August, 1917, with a view to a closer technical control over their operations. The very grave position in regard to shipments of sodium nitrate during the last two years of the war led to a project for an extensive national factory at Billingham for deriving nitrogen products from the atmosphere. The scheme passed through many vicissitudes. Erection of enormous national plants was no longer so simple a matter as in 1915. The original project of August, 1917, passed under the consideration of one committee of inquiry after another. The progress of the factory was seriously hampered by low priority, lack of labour and material, and in November, 1918, construction by the State was abandoned.[1]

(b) *Methods of Construction.*

The erection of enormous explosives factories for new or comparatively unknown operations presented very peculiar technical difficulties. Moreover, the number of chemical engineers with experience in this class of work was strictly limited. Indeed, it was very largely in order to make the best use of the expert knowledge available that the early decision was taken in favour of constructing national plant. The lay-out and erection of the factories at Oldbury and Queen's Ferry were the work of Mr. K. B. Quinan, who was also responsible for planning the Gretna factory. At Oldbury the agency firm undertook to provide labour and materials for the building operations. The construction of Queen's Ferry was more directly controlled from headquarters. For Gretna Messrs. Pearson and Sons were appointed construction managers with a large degree of autonomy. They were responsible also for the building of the townships, which were planned by the chief town-planning expert of the Local Government Board, Mr. Raymond Unwin. The purchase and inspection of plant and material

[1] 74./H.E.N./136.

for Queen's Ferry and Gretna was controlled by a member of the firm of Sir J. Wolfe-Barry. The provision of the huge water-supply needed by the new factories rested with a special adviser, Mr. Hawksley, appointed in July, 1915. The Contracts Section of the Explosives Supply Department was responsible for building and other agreements. By June, 1916, the pressure of construction work was becoming relaxed. Mr. Quinan's headquarter staff became the Factories Branch, controlling both the construction and administration of the national factories with the exception of Oldbury, Rainham and Gadbrook, which were administered by the Contracts Section, and of the wood distillation and cotton waste factories, which, together with the Royal Gunpowder Factory, were controlled by the Propellants Branch.

At the same time special experts were employed so far as was possible in connection with the building of particular factories. Thus a consultant engineer with particular knowledge of ammonal plant was appointed at Watford, and an agreement was also made for advice and assistance from the ammonal monopolists (Roburite and Ammonal Ltd.). Nobel's Explosives Company, Ltd., had completed the construction of Pembrey before it was nationalised. They, also, became responsible for the lay-out and erection of Irvine, for which they had special facilities. The three agency firms who undertook to construct picric acid factories in December, 1916, had already successfully established trade factories for the same explosive. At Langwith the process adopted for ammonium perchlorate needed special power plant and, in addition to a construction manager, special consultants on power gas were appointed.

The technical difficulties of construction were greatly enhanced by the novelty of the processes for which the factories were planned, while, in order to expedite construction, the details of the lay-out were often settled as building proceeded. The M.N.T. and T.N.T. plants at Oldbury were installed in a few months. The larger Gretna factory took a year in the building. The construction programme at Queen's Ferry was changed from time to time. The site was occupied in May, 1915, and guncotton was first produced in the following December. In this, and numerous other factories, the sections were divided into distinct units so that actual operation did not await the completion of the factory. With growing difficulties in obtaining labour and plant, the constructional work became more and more delayed. It has been seen, for instance, that the erection of the factory at Billingham was eventually abandoned as a war measure on this account.

Nearly all National Explosives Factories were built on a time-and-line basis, since the concurrent development of process made repetition work, except for the comparatively small proportion of brick-work, quite impracticable. The disadvantages of this method were, however, experienced to the full. At Avonmouth, for example, a fifty per cent. reduction in the number of construction labourers made no perceptible decrease in results, while the quality of the work was often far finer than was necessary. The explosive factories were

particularly costly, owing mainly to the exceptional character of their plant and the experimental nature of much of the work which was undertaken. As a class they were also exceptionally numerous. They included some 33 factories and were equalled in number only by the National Shell Factories. Moreover, several of them, such as Gretna, Queen's Ferry and Oldbury were on a scale enormously greater than any single trade factory, and such factories as Queen's Ferry and Pembrey were in fact a group of establishments undertaking several absolutely distinct classes of work. By March, 1919 the total cost of the entire class, including factories for explosives materials but excluding expenditure on schemes which were entirely abortive, had reached nearly £25,000,000.[1] The two abandoned projects at Henbury and Billingham accounted for another £876,900, allowing for Henbury £154,400, the sum to which special liquidation committees had by then reduced the commitments and actual expenditure, which originally amounted to £3,585,000.

(c) *Achievements of the National Explosives Factories.*

The need for so large an outlay on new state factories was partly due to the entire lack of industrial capacity for certain explosives, such as T.N.T., or for their materials, such as acetone. Even where the industry was well-established, *e.g.*, in cordite manufacture, the necessary rate of output could only be obtained by constructing new factories, for which no post-war use seemed to exist. Accordingly explosives contractors were unwilling to extend their works beyond a certain point. It was largely by means of the national factories, that the explosive programme was invariably met. At the outbreak of war, state production was restricted to the Royal Gunpowder Factory, which made about 75 (short) tons of cordite and gunpowder weekly. In remarkable contrast was the average weekly output of over 2,000 tons of all classes of explosive produced by the national factories during the year 1917, when state manufacture had been organised to the full. The most remarkable item in this figure was the average output of over 1,000 tons of T.N.T. from the national factories as compared with 520 tons, the average weekly figure from all other sources. Since nearly 50 per cent. of the propellant supplies was purchased from overseas and the manufacture of ammonium nitrate was chiefly in the hands of the trade, the general proportion of all explosives made in national factories to those obtained from other sources was considerably less than in the case of T.N.T. Nevertheless, the output of explosives from state factories during the year 1917 was little less than one-third of the whole supplies, while during the year 1918 it rose to rather more than a third of the whole.[2]

In all, the new national explosives factories, which were set up during the war, produced 236,251 (short) tons of high explosive and 81,341 (short) tons of propulsive explosive, in addition to large

[1] The figure to the nearest hundred pounds was £24,873,400.

[2] These figures are based on the *Review of Munitions Output*, 1914-18, pp. 82-85.

quantities of explosive materials. The main details of their output is shown in the table which follows.

Output of H.M. Explosives Factories.[1]

	1914	1915	1916	1917	1918	Total
High Explosive :						
Picric Acid	—	—	—	1,376	3,265	4,641
T.N.T.	—	3,675[2]	20,795	52,723	53,746	130,939
Ammonium Nitrate ..	—	—	—	19,194	81,477	100,671
Total High Explosive	—	3,675	20,795	73,293	138,488	236,251
Propellant :—						
Cordite	—	—	2,350	39,473	35,454	77,277
Ballistite	—	—	—	781	—	781
N.C.T.	—	—	—	—	3,283	3,283
Total Propellant ..	—	—	2,350	40,254	38,737	81,341

While the enormous output of these factories was of vital importance, they also served other essential purposes. Many of them, particularly those for T.N.T., provided a means of working out absolutely new processes on a large scale. The manufacture of T.N.T. in state factories also enabled the Department to consider questions of safety side by side with considerations of output, and so to avoid the rigidity of the safety conditions applied to trade factories which undertook dangerous processes. It was for this purpose alone, for instance, that the T.N.T. purification factory at Gadbrook was accounted a government establishment. The factories also served a very special purpose in reducing the usage of raw materials and in fostering every kind of efficiency. An intricate system of cost and efficiency returns was established in them for this purpose. This system gave rise to a general competition in economy not only between individual national factories, but also, in several instances, between the national factories and trade manufacturers. The technical and practical efficiency of the factories reduced very considerably the cost of making explosives, particularly those classes of explosive of which little experience existed. The great size of many of the factories also tended to cheapness of production. Hence, they provided a very economical source of supply as compared with the alternative of purchase from America or even from British contractors. The relatively low cost of production in the national factories was a direct cause of very considerable reductions in the contract prices for high explosives during the year 1917.

In the year 1918, a considerable part of the plant which had been installed for picric acid manufacture was closed down by reason of the decreased use of that explosive. The factories chiefly affected were

[1] Figures denote short tons.

[2] An approximate figure only.

those erected for the production of phenol. It was, however, found possible to convert a large proportion of this plant for the manufacture of poison gas.

(d) *Staff and Operatives.*[1]

One of the main problems in establishing the explosives factories was the provision of adequate numbers of trained works chemists and process-workers. The number of trained technical men, and more particularly of chemical engineers, was strictly limited. The technical staffs of commercial firms were already sorely over-taxed. It was necessary to fall back upon the young and usually inexperienced chemists of the country, who were mostly without either works experience or administrative knowledge. These were selected and trained as works chemists on existing plant as the various factories started work. Towards the end of 1915, it also became necessary to organise a system of training for chemist foremen, since experience showed that the normal method of advancing operatives as foremen after a lengthy period of instruction would be impracticable in the time available and under the comparatively inexperienced works chemists from whom the factory staffs were being drawn. The new class of chemical foremen was created from intelligent young chemists who were drawn first from Great Britain, and subsequently from the Colonies or the Special Brigade, and were trained in the actual working of the process before they were put in charge of a shift.

Apart from the difficulties experienced in providing technical staff, the provision of labour for the National Explosives Factories was easy as compared with the National Shell and Projectile Factories. Operatives in the explosives industry were normally unskilled men, who obtained their experience from working in the factories themselves. This practice was continued in the national explosives factories. Over 30,500 operatives were employed in them during the autumn of 1918. The chief change made was in the employment of women, who then formed about 51 per cent. of the whole number of employees.

II. Individual Explosives Factories.

H.M. Factory, Avonmouth.[2]

Early in the summer of 1916, when the services were demanding very large supplies of picric acid, it was decided to erect a single national factory to produce 350 tons weekly, the largest quantity it was then thought possible to obtain from the benzol available for British use. In August, 1916, a site at Avonmouth, near Bristol, was selected for the erection of sulphuric acid plant, to be fed from the zinc concentrates obtained from the National Spelter Company, who were simultaneously building a factory on an adjacent site for

[1] HIST. REC./R/1122.7/17.
[2] HIST. REC./H/1500/6, 1122.7/8; C.R./Filling/297; X.235/35; Southern 8/5315; 74/Avonmouth/1, 3, 94, 140.

roasting zinc ore. Early in the autumn the two schemes for picric and sulphuric acid production were combined, and by October, 1916, plans were completed for the establishment of a factory at Avonmouth next to the Spelter Company's works to contain both the sulphuric and picric acid plant.

The site covered nearly 249 acres on the banks of the Severn, 1¼ miles north of the Great Western Station at Avonmouth, and 1 mile from Avonmouth Docks. The land was private property and possession was taken under the Defence of the Realm Act, an annual rent of £472 being paid from September, 1916, in addition to compensation to the tenants. Sidings connected the factory with the Great Western Railway main line and railway transport was always satisfactory, while considerable traffic could reach the factory from the docks. The factory was directly controlled by the Factories Branch of the Explosives Supply Department and construction was begun by November, 1916. In March, 1917, the proposed picric plant was cut down by a third, and though much of the remaining plant was constructed by the end of 1917, its use for the production of picric acid was then abandoned before any output had been obtained. These changes were the result of the growing stringency in tonnage and the consequent abandonment of picric acid. Some of the picric acid plant was subsequently converted for mustard gas (H.S.) manufacture.

The plant for oleum (fuming sulphuric acid) had been planned on a larger basis than was needed for the picric acid plant in order to provide additional acid for the explosives and fertiliser programme. Ten grillo units were erected and of these one unit began work on 3 January, 1918, the first output of oleum being sent to H.M. Factory, Pembrey. Production from this one unit continued till August, 1918, when in view of the decreased demand for sulphuric acid, it was necessary to close down the grillo plant.

Early in June, 1918, it was decided that the bulk of the H.S. gas required should be made at Avonmouth and delivered to Chittening, 1½ miles away, for charging into shell. The factory was therefore laid out for the production of 500 tons weekly, the full output to be reached in December, 1918, but many difficulties developed and the greatest weekly output reached before the Armistice was 125 tons. When production began on 3 July, 1918, the factory was at first hampered by transport troubles and a month elapsed before an efficient system of tank wagons was evolved, in which the H.S. was conveyed to Chittening, where members of the Avonmouth staff transferred it to the charging-factory's drums. In the autumn, plans were made for laying down pipe lines from Avonmouth to Chittening, but these were not completed before the Armistice. The total amount of H.S. produced by 26 July, 1918, was 32 tons; but by the first week of August the output reached 10 tons daily and there was a prospect of speedy increase. On 21 August, however, it was necessary to cease manufacture in order to repair and clean the plant, as owing to an accident to the ethylene plant, the vessels and tanks had become impregnated with sulphur. Production began again on 4 September, 1918, at 5 tons daily, and it was hoped very quickly to attain a good output. On 23 October, however,

the factory was again closed, since practically all of the technical staff were incapacitated, partly owing to climatic conditions which intensified the difficulty of ventilation. The quality of the H.S. produced varied from time to time, and the Chittening factory had considerable difficulty in handling the product from Avonmouth. The chief obstacle to increased output was sulphur deposition, and just before the Armistice certain alterations were carried out which dealt with this problem.

Much difficulty was experienced in obtaining skilled labour both for construction and production, and about 50 per cent. of the skilled workers employed were imported through various enrolment schemes. As this additional labour could not be accommodated in Avonmouth 99 per cent. had to live at Bristol. A very efficient train service was provided for these and the Ministry also set on foot a housing scheme to provide workmen's cottages at Shirehampton, a village two miles from the factory. Owing to the experimental nature of the lay-out, the work of construction was carried out on the "time-and-line" basis, which did not prove the most economical form of contract, the number of workmen employed being at one time reduced from 4,300 to 2,000 without any appreciable decrease in the work accomplished, while the quality of the work was much finer than was required for such a factory. Women were employed as construction labourers on the grillo unit, and later on the ethylene plant for H.S. production and their output on both processes compared favourably with that of male labour. Construction was hampered on several occasions by labour disputes as to the rate of wages, while later the question of women's wages became the subject of much dispute and was submitted to arbitration. When the factory was producing H.S. the very high proportion of labour casualties, amounting at one time to 70 per cent. of the labour employed, spread a feeling of considerable alarm in the neighbourhood, and greatly increased the difficulty of obtaining workers for the factory. Owing to the nature of the work on H.S. frequent periods of rest or work away from the gas were necessary. The number of workers employed at the factory in October 1918 was 224, of whom 39·3 per cent. were women.

The cost of the factory for picric and sulphuric acid production was estimated at the end of 1917 as £1,400,000, but the actual figures differed widely from estimates owing to the changes in programme which followed. The grillo plant was shown to be the cheapest producer of SO_3 of any plant under the Ministry's control; but the picric plant, costing £300,000, was never put to its proper use, and only certain units were subsequently converted to poison gas manufacture. The actual expenditure to March, 1919, was £1,578,200.

H.M. Factory, Bradley.[1]

The national factory at Bradley, in Yorkshire, was one of the three factories planned in December, 1916, of which each was to produce 80 tons of picric acid weekly.[2] The factory was managed by Major L. B.

[1] 74/Lytham/14; HIST. REC./R/400/57, 1122/45; HIST. REC./H/1500/6; 74/Bradley/1, 51; X/Bradley/2/1.

[2] *See* below, under Lytham, p. 66.

Holliday, and the agreement for erection and management differed slightly from those signed by the firms at Lytham and Greetland in that, in this case, the fee for construction was £3,000, and the remuneration for management of $\frac{1}{10}$d. on each pound of picric acid produced was only calculated on picric which was up to government specification, though in the other two cases the pure picric contents in the waste picric produced were included. The firm also had the option to purchase the factory under certain conditions.

The site selected covered an area of rather more than 26 acres, near to Major Holliday's works at Deighton, but separated from them by a railway embankment high enough to prevent any danger to one factory from the other. It was bounded on the one side by the railway and on the other by a canal, and the factory was thus assured of good transport facilities by rail or barge. The land was the property of private owners and of the Midland Railway Company, and possession was taken under the Defence of the Realm Act.

Construction began in January 1917, while Major Holliday was carrying out experiments in his own works, with a view to developing an improved process for picric production. In February and March, work was almost suspended owing to the delays which occurred in laying the necessary sidings and the consequent non-arrival of plant. Arrangements were made with the Huddersfield Corporation for the disposal of the effluent, a matter of considerable difficulty. In November, 1917, an elaborate installation was begun for drawing an additional water supply from the River Calder. In February, 1918, when the demand for picric acid had diminished, arrangements were made for the completion of the factory and the carrying out of experimental runs to demonstrate the process ; but for these the quantities dealt with were to be as small as possible and no regular production was to be undertaken. After 30 April, 1918, only the staff necessary to keep the plant from deterioration was employed.

As Major Holliday's experiments had proved satisfactory, the plant at Bradley was set up for a new process for converting synthetic phenol into picric acid, somewhat similar to that commonly adopted for manufacture from dinitrophenol. All the waste acid was to be reconcentrated, and, though during experimental work the cost was high, owing to the very strong acids used, it was thought that when the factory was in full working order the new method would give a better yield of picric at less cost than the old pot process. After some trials had been carried through, it was decided to cease production of picric in the firm's own works on 30 June, 1918, and begin in the new factory on 1 July, but, though deliveries stopped from the firm, the factory could not be started owing to the serious effects of the influenza epidemic.

In September, 1918, part of the plant was running with a production of about 10 tons weekly, but the work was still of a somewhat experimental nature, and a considerable amount of construction was still in progress. Some improvement was made in October, and by the end of the month despatches amounted to upwards of 30 tons, but after the Armistice only a small amount of drying and repacking was carried on.

The labour requirements of the factory were estimated in January, 1917, at 150 men and 70 women, and both men and women were employed in 1918. The total number of employees in October, 1918, was 370, of whom 21·1 per cent. were women.

The estimated capital expenditure was £360,000, the cost of the plant being reckoned as £110,000. Owing to the short time during which the factory was at work, it was impossible to make any actual tests of the comparative costs or efficiency of the plant. The capital expenditure to March, 1919, was £369,500.

H.M. Factory, Craigleith (Edinburgh).[1]

The national factory at Craigleith, which was established in 1916, was the last of those built for the production of T.N.T., and was operated as an agency factory by the Lothian Chemical Company. This company had been formed in the early summer of 1915 by a professor of chemistry of Edinburgh University, his assistant and a works manager, to erect plant in Edinburgh for the manufacture of T.N.T. They had proved most successful contractors, but they had been instructed to cease work in June, 1916, owing to the danger arising from the position of their explosives factory in the centre of a congested area in the city. At the same time, to utilise the excellent works practice and chemical skill of the staff, projects were considered for a new factory at Craigleith, some distance out of Edinburgh. As the company's available capital was limited, the Government decided to erect the new factory as a national establishment, to be managed by the company as agents.

The Craigleith site was taken over under the Defence of the Realm Act on 14 April, 1916, and the agreement for the management was signed on 20 June. By its terms the company undertook the entire design and lay-out of the factory and the supervision of its erection and equipment, receiving a lump sum remuneration. The Ministry was to pay all capital expenditure, and when production began was to be responsible for working costs, while the company received a management commission varying from 1*d*. to $\frac{3}{8}$*d*. on every pound of T.N.T., according as the cost of production ranged from £75 to £95 a ton. A subsequent revision of the agreement, made in view of changes in the T.N.T. specification, increased the erection fee to £2,650, and raised the sliding scale.

The works were laid out for a capacity of 35 tons weekly, and it was hoped to complete construction by the end of 1916. In December, however, it appeared that the plant was not well balanced, and it was decided that, while rectification of this matter was in process, the whole capacity should be raised to 50 tons weekly. Some trouble also occurred on the concentrators, and production was not actually started until February, 1917. The full rated output was reached by 10 November, 1917.

The process was very carefully controlled by the chemical staff, and the use of material was economical. The chief difficulty arose

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[1] 74/L./61,164 ; 74/Craigleith/2, 6, 12, 82, 88, 95 ; C.R. 2913.

from the imperfect working of the concentrators, which permitted a considerable escape of noxious fumes. These gave rise to complaints from the city authorities, and rendered working conditions unsatisfactory. Some cases of toxic jaundice occurred among the women workers, and were attributed to dusty surroundings and bad handling, but steps were taken in August, 1918, to remedy these defects and improve the welfare conditions generally, and the proportion of sickness was not high compared with that in other works of a similar nature. The total number employed in the factory was, roughly, 300 in the spring of 1917, and had increased to 412 by October, 1918, when the proportion of female labour was 44·4 per cent. of the whole.

On 11 November, 1918, instructions were sent to the manager to cease manufacture as soon as possible, and it was estimated that actual production would stop at the end of the month.

The original estimate of capital expenditure on the factory was £40,940. Subsequent additions raised this figure, and the actual expenditure to March, 1919, was £67,900.

H.M. Factory, Ellesmere Port.[1]

This factory was built on five acres of land in Cheshire, originally rented from the Ship Canal Portland Cement Company. Later, in September, 1917, the freehold of the land was purchased. The site was chosen largely on account of its accessibility by means of the extension of an already existing railway siding, and also by means of the Manchester Ship Canal, beside which it lay. The proposal to erect a government factory for the production of 10 tons of synthetic phenol a day was made when, in October, 1915, it became clear that in order to provide for the picric acid programme it was necessary to increase the supplies of phenol. The standard method of manufacture was used, *i.e.*, synthesis from benzene through benzene sulphonic acid, and the process adopted had, in common with all others, the two stages of sulphonation and fusion. The details of neutralisation, etc., were, however, peculiar to the process, and preliminary experiments were carried out with experimental plant at University College before the design of plant and general lay-out was embarked on. The drying process adopted was protected by a patent, the rights of which were vested in Messrs. Brunner, Mond. They agreed, however, to allow the Government to use the process for the production of munitions of war. The construction of the factory was begun in March, 1916. It was completed in February, 1917. Some delay was caused both by scarcity of labour and by an extension of the original design. The area of the buildings erected was 410,601 square feet. From the first the factory was directly controlled by the Explosives Supply Department.

The original lay-out was for an output of 10 tons of phenol a day, but before the completion of the general lay-out it was realised that the housing accommodation of nearly every plant unit was sufficient to allow of an ultimate extension of plant to produce 15 tons a day.

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[1] Hist. Rec./H/1122.7/16.

It was therefore decided to make the buildings uniformly capable of housing the additional plant necessary for such an output. Production began in May, 1917, and the maximum output of 70 tons a week, for which the factory had been planned, was reached by March, 1918, when the factory was about to be closed by reason of the decreased demand for picric acid. The total output of phenol was 878 tons. In June, 1918, however, a proposal was on foot to use the factory for the manufacture of poison gas, and in July it was decided that Ellesmere Port should meet a demand for certain arsenic compounds. Some alterations and new plant were required. The estimated output of 40 tons a week was not at first realised; but the factory produced nearly 200 tons of arsenic compounds between August, 1918 and the date when it was finally closed down.

Owing to the urgency of the demand for poison gas, military labour was employed both for construction and subsequently for process work in connection with production. At the end of 1917, 386 workpeople were employed, 35·2 per cent. being women. In October, 1918, the total number was 249, and only 7·6 per cent. were women.

The capital expenditure down to 31 March, 1919, was £160,800, and was inclusive of the cost of converting plant for poison gas manufacture at an outlay of about £20,000.

H.M. Factory, Gadbrook.[1]

The factory for T.N.T. purification at Gadbrook was built on 59 acres of land in a sparsely populated district about two miles from Northwich. Part of the land was held by agreement with Messrs. Brunner, Mond at a rental of £3 per annum and the remainder was taken over under the Defence of the Realm Act at a rental of £2 per annum. The buildings, which were erected at the cost of the Government, covered an area of 95,135 square feet. The Ministry had an option to purchase the land within one month of the termination of the agreement, and if this option was not exercised the company might buy the works.

The factory was erected solely in order to meet the need for additional plant for T.N.T. purification by the early methods involving the use of alcohol, since in the spring of 1915 it was found that the Rainham factory could not treat the quantities required, and it was not considered desirable to erect purification works in the same place as manufacturing works on account of special danger risks consequent on the use of alcohol. In May, 1915, Messrs. Brunner, Mond were invited to carry out experiments with a view to devising a less costly and speedier process than those in use, and towards the end of the month experimental work was done by the firm at their Winnington works, information having first been obtained from Messrs. Nobel's, and the Clayton Aniline Company on the methods they employed, under guarantee that such information should only be used for government

[1] 74/H.E.T./139, 379; 74/Explosives/75; Hist. Rec./H./1520/5; D.G.M.D./E/32: X237/21.

purposes. On 5 June, 1915, the firm undertook to erect plant within two months for the treatment of at least 15 tons of T.N.T. daily. The loss of the supply of purified T.N.T. from Ardeer consequent on the explosion there in July, 1915, made it still more imperative that new purifying factories should be at once provided,[1] and after first adapting a stand-by caustic soda plant at their own works at Silvertown for the purpose, Messrs. Brunner, Mond proceeded to build the new and much larger purification works at Gadbrook.

The first sod was cut at Gadbrook on 19 July, 1915, and installation of the plant began in November, 1915. The first unit was completed in February, 1916, a second unit (in which improvements were made on the first) on 12 July, 1916, and a third on 27 December, 1916. In planning the construction of the factory, special arrangements were made against fire risks, and in June, 1916, a magazine was added with a view to increasing safety. A further extension was a T.N.T. grinding plant added in May, 1917.

The method of purification used throughout at Gadbrook was that of alcohol washing, but after a disaster at the Silvertown works at the beginning of 1917, much experimental work was done on safer methods of purification, and a plant for water washing was installed at this factory. This, however, did not go beyond the experimental stage, for with the further development elsewhere of a sulphite purification process the method of purification by washing with water lapsed.

The factory was throughout operated by Messrs. Brunner, Mond. Originally the firm were in the position of contractors working for a management fee of 5*s*. per ton of product. On 22 August, 1917, after the destruction of the Silvertown works and of a contractor's factory at Hooley Hill, the Order in Council which had previously exempted T.N.T. trade factories from the main provisions of the Explosives Act, was repealed. In order to avoid the application of stringent safety conditions to the unique and urgent operations carried out at Gadbrook, the factory subsequently ranked as a Government agency factory for the purpose of safety conditions.

The capacity of the factory was 75 tons per day, *i.e.*, 525 tons per week. Output began in February, 1916, and by July, 1916, it had reached 200 tons a week. At the end of March, 1917, orders were given to double this rate, and still further increases were asked for in July, and at the beginning of December, 1917. The maximum output was reached in the week ending 14 December, 1917, when 510 short tons were purified, but with the labour then available 450 tons per week was the average output. In March, 1918, a reduced output was ordered, and from May to the date of the Armistice, when operations ceased, only 120 tons per week were required. In all 34,131 tons of crude T.N.T. were treated, from which 31,197 tons of pure T.N.T. were obtained.

As regards labour, soon after process work began, shortage of male labour led to the decision to employ women, and these were first

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[1] 74/Explosions/75.

employed on 21 March, 1916. Great labour shortage was experienced in the spring of 1917, but this was relieved by a draft of 137 men from Avonmouth. During the winter of 1917-18, when production was at its highest, 1,050 operatives were employed of whom 52 per cent. were women.

The total capital expenditure, as estimated in July, 1918, was £195,000.[1]

H.M. Factory, Greetland.[2]

As part of the scheme which was developed in December, 1916, for extending the production of picric acid in the country, Messrs. Sharp and Mallett undertook to erect and manage a factory at Greetland (Yorks.) and an agreement was drawn up on the same lines as that for the Lytham Factory.[3]

Possession was taken under the Defence of the Realm Act of a very convenient site covering rather more than 15 acres on the river Calder, two miles from Halifax and close to Greetland station. The main road from Halifax to Huddersfield bounded one side, and the Lancashire and Yorkshire Railway the other, the railway embankment being sufficiently high above the site level to make the handling of raw materials simple and cheap. Thus, for instance, sulphuric acid could be run by gravity from tank-wagons to storage boilers, and thence to various parts of the factory. The site was owned by the Halifax Corporation, and by the Lancashire and Yorkshire Railway, and use was made of a few old buildings belonging to former tallow works.

Construction of the main works was begun at the end of January, 1917. Considerable difficulty was experienced in laying foundations, since the site was sandy and consisted of an old river bed. The task was eventually accomplished and the factory started work in August, 1917, delivering the first output in September.

Steady progress was made during the autumn, although the factory was never required to reach its estimated output of 80 tons. The lay-out was admirably planned for economy and efficiency, and the plant well designed and fitted, while during the factory's working various improvements in method and plant were developed with a view to the increasing of efficiency and safety, and the reduction of costs and labour figures. The cost of nitric acid production at Greetland was £1 per ton cheaper than that of any other nitric plant controlled by the Ministry, and in spite of the constant rise in wages and prices, the improvements evolved by the management and chemical staff considerably reduced the cost of picric. Though the processes in use at Greetland and Lytham were identical in theory and nearly so in practice, the average cost of raw materials per ton of picric acid produced was £28 less at Greetland. Production was accordingly continued in 1918, and in April the factory began delivering undried "service" picric for poison-gas manufacture to replace the "waste picric" formerly

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[1] X235/47.

[2] HIST. REC./R/1122.7/18, 1122.7/6, 1122/45, 400/57; HIST. REC./H/1500/6; 74/Lytham/14.

[3] *See* below, p. 66.

used for this purpose. After the Armistice, production was stopped, but for some time the factory was engaged in drying wet picric and repacking stores which had deteriorated.

Considerable difficulty arose in obtaining sufficient labour, and in November, 1917, output was restricted by lack of workers. The scarcity was relieved after the closing down of neighbouring works at Copley and Wyke, and dilution was carried out to a considerable extent, the women proving quite satisfactory on the lighter kinds of work. In October, 1918, there were 339 employees, of whom 24·2 per cent. were women.

In June, 1917, the capital expenditure was estimated at £160,000, and by March, 1919, the actual expenditure was £183,600.

H.M. Factory, Gretna.[1]

The large and important propellants factory at Gretna was erected on a tract of marshy land forming the north coast of the Solway Estuary and stretching across the border. Gretna itself is only about 8 miles from Carlisle, but the site covered over 9,000 acres, and consisted of a strip of land, roughly 9 miles by one, lying between the Glasgow and South Western Railway on the north, and the Solway Firth and the River Esk on the south. It extended from Dornoch Village on the west, to Longtoun on the east, and was served not only by the Glasgow and South Western, but also by the Caledonian and the North British railways.

The initiation of the factory was due to the Munitions of War Committee, who, on 13 May, 1915, recommended that a largely increased production of some substitute explosive suitable for land service should be arranged, in order to free service cordite for the use of the Admiralty. At the request of the committee, Lord Moulton considered the practicability of establishing a new source for an output of 2,000 tons of propellant monthly, and in conjunction with Sir Reginald Sothern Holland, he drew up a plan for making the whole quantity in a single factory. On 27 May, 1915, he recommended that the new factory should make cordite R.D.B., which had just been evolved by the Research Department, and was made from the solvent ether-alcohol in place of acetone, of which supplies were short. During the month of June, preparations for the new factory were continued, and on 26 June, Mr. Lloyd George, as Minister of Munitions, gave formal authority for its erection. The main problem as regards site was to find an isolated area of sufficient size, with an enormous supply of water, suitable for explosives manufacture. Towards the end of June the site was fixed at Gretna, where a water supply of close on ten million gallons a day was eventually drawn from the River Esk. The area, first taken under the Defence of the Realm Act, in July, 1915, consisted of 7,715 acres of lightly-farmed arable and pasture land, and an additional 1,399 acres were subsequently taken. It was further decided that in addition to making up its own nitrocellulose

[1] Hist. Rec./H/1122.7/11, 17, 19, 25; Hist. Rec./H/346/5; Hist. Rec./R/172/1, 172/7, 263.5/5.

into cordite, the factory should be made capable of dealing with the nitrocellulose produced by H.M. Factory, Queen's Ferry, the total annual output expected being some 40,000 tons of cordite per annum, *i.e.*, about 3,300 tons per month, in place of the 2,000 tons per month originally proposed.

The actual lay-out and detailed planning of the factory was carried out at the Explosives Supply Department, under the personal direction of Mr. K. B. Quinan. The factory was divided into several "areas." That at Dornoch (area 1,203 acres) comprised the glycerine distillery, and the acids, nitrocellulose and nitro-glycerine sections. From the Dornoch Area, the pastê was despatched eastward to the Mossband Area (1,381 acres), where it was made into cordite. In this area there were eight units or ranges widely dispersed for the sake of safety. Thence the finished cordite was sent to magazines in what was known as the Longtoun Area (258 acres). Not far from the Mossband Area, was a separate ether section which supplied the ether-alcohol solvent. The solvent recovered in the cordite section was returned to this ether section for distillation. The site (10 acres) chosen for the central electric power station was at Rigg, between the Dornoch and Mossband Areas, while the water intake and pumping station (5 acres) lay a short distance above Longtoun. Reservoirs and filters covered 14 acres. The above were all fenced areas patrolled by the military guard, and used for factory operations. The remaining land was used for the erection of townships and for agricultural and general purposes.

Agreements were made with various contractors and construction began in August, 1915. In the autumn of 1915, in order to expedite the erection of the factory, a large and experienced firm of contractors (Messrs. Pearson & Son, Ltd.) were entrusted with the entire direction and management of the construction and erection of the factory in accordance with the plans and designs provided by the Minister's technical advisers. They undertook this task with the title of "Construction Managers," and a measure of discretion substantially larger than is usual was conferred upon them in order to secure the requisite expedition. The various sections did not, of course, start up simultaneously. Among the earliest working were the Mannheim oleum plant (June, 1916), and the glycerine distillery and nitric acid retorts (July, 1916). Output of the final product from Gretna paste began in August, 1916, though the cordite ranges began to produce from Messrs. Nobel's paste two months earlier. The factory was controlled by the Factories Branch of the Explosives Supply Department, and was under the management of a superintendent.

The factory dealt not only with its own, but also with imported nitrocellulose. The capacity of the factory nitrocellulose plant was 350 tons per week, while the quantity of nitrocellulose to be imported was estimated at 200 tons per week. The nitro-glycerine necessary to mix with this was made from pure glycerine produced from imported crude glycerine at the glycerine distillery, which was the only State-owned plant for purifying glycerine. The capacity of the nitro-glycerine plant was 800 tons per week, and that of the glycerine distillery was

240 tons per week. The nitric and sulphuric acids necessary for consumption were made in the acids section, nitrate of soda, pyrites and sulphur being imported for the purpose. The sulphuric acid (in the form of oleum) was made by the contact process on both Mannheim and Grillo plants, the capacity of the former being 280 tons SO_3 per week and of the latter 560 tons SO_3 per week. The nitric acid retorts were capable of producing 800 tons HNO_3 per week. The acids section also included the plant necessary for denitration, concentration and acid mixing. The capacity of the ether plant, which produced ether from imported alcohol, was 1,570 tons a week. Although the factory was planned with a view to an output of 800 tons of R.D.B. cordite per week, it was capable of a maximum output of 1,000 tons per week. The full output of 800 tons per week was attained early in 1917, and the total output from the opening of the factory to 28 January, 1919, was 56,876 tons.

It was estimated in June, 1915, that the factory was likely to employ between 10,000 and 15,000 workers. Since it was impossible to find neighbouring accommodation at Carlisle and elsewhere for such a number, the decision was made to erect factory townships. The Local Government Board was consulted by the Explosives Department, and the townships were planned by Mr. Raymond Unwin, chief town-planning expert of the Local Government Board, whose services were borrowed for the purpose. The two principal townships were Gretna (area, 431 acres) in the central part of the factory area, and Eastriggs, near Dornoch (area, 173 acres) on the western extremity of the factory area. At both of these townships, churches, schools, public halls, post offices and shops were provided. Some houses were also erected at Gartleburn, Mossband and elsewhere. The development of this entirely new community and the organisation of its social life have been described elsewhere.[1] Originally, large numbers employed on construction were housed in the townships and the staff and operatives of the factory did not come into full possession till August, 1917. The maximum number of construction and operating workers employed together was 24,000. The maximum number of operating workers employed was 19,772 (October, 1917), but the efficient organisation resulting from experience made it possible to economise labour and the number working in October, 1918, including staff, was 11,511.

The problem of female labour at Gretna was unique. The proportion of female to male labour was about 70 per cent. to 30 per cent. in the summer of 1917, but at the time of the Armistice, the number of women had decreased to 60 per cent. of the whole. There was no possibility of drawing the full number of women required from the locality, and between five and six thousand had to be brought from all parts of the country. This necessitated special "welfare" organisation, not only in the factory itself, but also in the factory townships.

The estimated expenditure, including the cost of the housing scheme, as calculated in November, 1915, was £2,000,000, and in August,

[1] Vol. V, Part V, Chap. VIII.

1916, it was £5,000,000. The actual expenditure far exceeded that sum. Treasury sanction was obtained for £8,500,000 in June, 1917, and the actual cost of the factory and townships down to 31 March, 1919, was £9,295,200.

H.M. Factory, Hackney Wick.[1]

This factory, formerly known as the Phœnix Chemical Works, White Post Lane, Hackney Wick, covered an area of 9,174 sq. yds. The nearest goods station was three-quarters of a mile distant, and the water supply was obtained from the River Lea. It was originally operated by a contractor, Mr. D. Bagley, under an agreement negotiated in October, 1914. He purchased the works on 29 January, 1915. The War Department undertook to advance the capital for this purchase and for the adaptation of the plant; to supply, free, the raw material for T.N.T. production, in quantities based on the supervisor's report during the third, fourth and fifth weeks of production; and to pay a fixed price of 3*d*. per lb. of T.N.T. produced and delivered under contract, plus the cost of material used by the contractor, a price being fixed for nitric acid and toluol. The factory and plant were to be the property of the contractor, charged with repayment of advanced capital, plus 5 per cent. per annum, but if he fulfilled all his obligations the interest was to be waived. Production was to begin within 3 months of the agreement, and the ultimate capacity of the plant was estimated to be not less than 15 tons of T.N.T. per week, and sufficient nitric acid for the T.N.T. manufacture. The works were originally laid out for the French method of production and afterwards modified to use the Research Department process No. 1. At the end of June, 1915, no output had been obtained, and the Explosives Supply Department, ascribing the failure to the contractor, took over the factory on 9 July, 1915. Purchase of the factory was considered preferable to seizure under the Defence of the Realm Act, as this would have entailed restoring to the contractor after the war, works in which he had invested no capital, and the change in process upon which the Department had insisted, prevented the enforcement of a penal clause. The purchase was completed on 10 June, 1916.

The first unit began output towards the end of July, the second, on 2 October, 1915, and from that date a steady progress was maintained; 84 tons of T.N.T. were produced during December, 1915. The maximum capacity was estimated in April, 1916, at 25 tons per week, and the nitrating plant was subsequently extended in order to bring the capacity up to 35 tons weekly.

Labour was principally male, and in January, 1917, only 13·8 per cent. of the total (189) were women.

In April, 1917, it was decided to close the factory on account of the congested area in which it was situated, but to keep the plant in condition as a stand-by factory.

The capital advanced under the contract of 29 December, 1914, was £24,000, and an additional sum of about £16,000 was sanctioned

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[1] 74/B./38; 74/B./368; C.R. 2913; (Printed) *Statement of T.N.T. Contracts February*, 1915.

by the Treasury on 24 September, 1915, for change in process. The purchase money paid by Mr. D. Bagley for the works amounted to £6,000, plus £75 for fittings. The additions and alterations finally made, brought the actual cost of the factory up to £66,200, by March, 1919.

H.M. Factory, Irvine.[1]

H.M. Factory, Irvine, was laid down in order to provide a British source of supply for nitro-cellulose powder of the American type and so reduce large overseas purchases which were undesirable on account of the financial situation. The construction of a much larger factory for the production of nitro-cellulose powder at Henbury was planned contemporaneously.

The site of the Irvine factory, covering 222 acres, was acquired in the latter part of 1916, from the Duke of Portland at a yearly rental of £750. It was situated three-quarters of a mile to the south of the Burgh of Irvine, and was bounded on the east by the Glasgow and South Western Railway, the proximity of this railway greatly facilitating the transport of goods and workers. The water supply for the factory was drawn from two sources, namely, the waterworks of the Irvine and District Water Board, and also the works of the Troon Corporation at the Collenan Reservoir. Electric power was supplied to the factory from the works of the Kilmarnock Corporation situated five miles distant.

Building operations were started in January, 1917, but the work of construction was not hastened as the entry of the United States into the war on 6 April, 1917, materially altered the situation. Importing the finished product from America involved considerably less tonnage than importing the necessary raw materials, and the shipping position was becoming increasingly grave. Accordingly the construction of the factory at Irvine was only proceeded with slowly under low priority, while the Henbury scheme was entirely abandoned.

H.M. Factory, Irvine was erected and operated under an agency agreement with Nobel's Explosives Company, who had a working arrangement with the Du Pont de Nemours Powder Company of America that all processes should be worked in common, a royalty being paid on those perfected after July, 1914.[2] They and one other firm had previously made small quantities of nitro-cellulose powder for foreign States, and with this one exception, no other firm in this country had had any experience in the production. In June, 1917, Du Pont de Nemours agreed that so long as existing conditions continued the British Government might make their improved form of nitro-cellulose powder free of royalty. The factory was laid out for the production of 100 tons per week of ordnance powder and 50 tons per week of rifle powder. The manufacturing plant was arranged in three sections namely, acids, nitro-cotton and powder. Parts of the plant and processes were arranged on lines following the latest American practice and hitherto not used in this country, and many difficulties directly connected with the novelty of the plant were encountered during the

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[1] Hist. Rec./H/1122.7/8; Hist. Rec./R/1530/11. [2] X235/35.

initial stages of manufacture and gradually overcome. Work began in February, 1918, with the re-conditioning of some lots of American nitro-cellulose powder damaged in transport, and ordinary service production began in April. Although substantial progress was made, maximum output was not reached at the cessation of hostilities, when instructions were given to cease operations. The total production of the factory for the period during which it was working was 118 tons of reconditioned powder, 926 tons of cannon powder and 140 tons of rifle powder.

As the factory was situated in the centre of a busy industrial district, an adequate supply of labour was obtainable and it was not necessary to inaugurate housing schemes. The greater part of the process work was carried out by women, but the supervising staff were entirely men and no dilution of skilled trades labour was undertaken, *e.g.*, among plumbers, fitters, joiners, etc. The numbers employed in October, 1918, were 1,568; the percentage of women being 73·2.

The total outlay upon the factory to 31 March, 1919, was £953,200.

H.M. Factory, Langwith (Mansfield).[1]

A factory for the manufacture of ammonium perchlorate was constructed at Langwith on ten acres of land rented from the Langwith By-Product Company, Ltd. Langwith is approximately 8 miles from Mansfield on the Midland Railway, 20 miles from Nottingham and 26 miles from Sheffield. The site was chosen largely because of the existence, contiguous to the pits of the Sheepbridge Colliery, of a Mond gas recovery plant owned by the Langwith By-Products Company from which gas and ammonium sulphate might be obtained. The decision that the factory should be constructed, in order to secure independence of Sweden for the supply of ammonium perchlorate, was made in 1915. France, with Sweden, had been a source of supply at the outbreak of the war but the output of the former had been rapidly absorbed by her own demands. The process developed and owned by a Swedish firm was adopted and a contract for the use of the process on a royalty basis was entered into in September, 1915. Contracts were also executed with the Langwith By-Products Company for the production of gas and bye-products and with the National Gas Engine Company for the construction of an up-to-date gas engine plant. The Power Gas Corporation were appointed consultant engineers on the power plant.

The process involved the electrolytic conversion of common salt to sodium perchlorate and the chemical production of ammonium perchlorate from this latter product by double decomposition with ammonium sulphate. Sodium sulphate in the form of Glauber Salt was to be produced as a bye-product from the chemical operation.

The excavations and buildings were begun in November, 1915. The first load was taken in the electrolytic section on 29 October, 1916. Running difficulties arose, however, at the very outset in the

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[1] *H.M. Factory, Langwith*; 74/S./159, 246, 314; 74/Langwith/3, 4, 8, 10, 14, 21, 50, 162, 216.

electrolytic section, and later in the chemical section, and output did not begin till June, 1917. The administration of H.M. Factory, Langwith, differed originally from that of other government factories managed from headquarters, as regards the position first of the Power Gas Corporation as consulting engineers and then of the construction manager appointed. In July, 1917, however, a reorganisation of the staff took place and a superintendent was appointed. From this time the management of the factory was in line with that of similar factories controlled directly from headquarters.

The factory was laid out to produce 3,000 short tons of ammonium perchlorate per annum or 50 long tons per week. The original output beginning in June, 1917, was very small. At the end of August, a new process for the chemical section of the manufacture was discovered which simplified and reduced the number of stages.

By the end of September, this was in actual operation, but it took some time to work out all the details of practical running, and the progress was interrupted by two explosions attended by fatal results. In July, 1918, full output was reached, and from July to November the average output was well over 50 tons per week. The total output from June, 1917, to 14 December, 1918, was 2,173 tons of ammonium perchlorate.

There was some scarcity of labour and this helped to retard construction. As regards dilution of labour, women did not replace skilled men except in the case of acetylene welders, but they were used successfully in both semi-skilled and unskilled work. In September, 1918, of 705 employees, 372 (52·7 per cent.) were women.

The workers were drawn from a radius of 8 miles, served almost entirely by the Midland Railway Company. A government village was erected half a mile from the factory on 5½ acres of land taken under the Defence of the Realm Act. It housed those of the staff and operatives whom it was necessary to have within reach of the factory. The actual capital expenditure down to 31 March, 1919, was £717,400.

H.M. Factory, Litherland (Liverpool).[1]

The explosive factory at Litherland was established as a trade venture in November, 1914, by Messrs. Brotherton & Company, a firm of tar-distillers with a command of large toluol supplies. It was set up on ground adjacent to the company's own works, and derived power from the same steam-generating plant. Lying 4½ miles to the north of Liverpool, the site was connected by sidings with the Lancashire & Yorkshire Railway, and a densely populated area to the south-west afforded an excellent labour field with convenient housing accommodation. The land originally occupied subsequently proved inadequate and additional ground was acquired at intervals, bringing the final area covered by the factory to more than 11 acres.

The factory was intended to meet the whole demand for T.N.T. for filling small natures of shell for the 1915 campaign, viz., some 500,000

[1] Vol. X, Part IV, Chap. IV; 74/B/372, 486; C.R. 2913; 74/Litherland/30. 60, 156 189.

pounds, and delivery was promised between December, 1914, and September, 1915. After construction had begun, however, it was considered impossible to bring so large a plant into operation in so short a time, and in March, 1915, a government representative was appointed to expedite the starting up of the factory. In view of the urgent demands for T.N.T. he was authorised to increase the capacity of the works from 50 to 100 tons weekly by ordering additional plant at the expense of the State, and to exercise a general supervision over the management at the factory. This arrangement proved impracticable owing to the indefinite relations of the Ministry's official to the firm, and the difficulties inherent in divided control. Repeated delays occurred in the course of equipment, the recommendations of the Department were neither thoroughly nor quickly carried out, and by the spring of 1916 the output was rarely more than 20 tons weekly. The inadequate supply of steam was a source of trouble for some time, but was partially remedied later by the introduction of fuel economisers and the substitution of electric motors where possible. In March, 1916, the Department took over the direct control of the factory, and there followed a period of re-organisation and expansion. The 50 tons output of the original estimate was reached in July, 1916, but progress was hampered by a shortage of nitric acid due to the ill-balanced lay-out of the plant, while in November, 1916, when it was decided that the T.N.T. must be granulated, new plant was required for the purpose. During the winter a further re-organisation of the management took place, and the output was not raised to 100 tons weekly until June, 1917. Even at this date the Superintendent did not consider that the rated output could be maintained, in view of the unsatisfactory condition of the plant. The failure of the concentration plant to absorb nitric fumes gave rise to various complaints in the neighbourhood, and made working conditions so bad that in 1918 the earlier difficulties were enhanced by a shortage of labour. The process in use was that of nitrating in three stages, and involved extensive handling of the material. When the numbers employed were too few to cope adequately with the work mishaps frequently occurred, and the machinery was so constructed that repairs required in any part delayed all the process, while the inadequacy of intermediate storage caused delay in any section to affect the whole output. In the earlier stages of the factory's operation dilution was difficult to effect owing to the scarcity of competent supervisors and forewomen. At the date of nationalisation the proportion of women to men was very small, and in July, 1917, was only 66 to 434, but the number was gradually increased until in March, 1918, the female labour formed 33 per cent. of the whole number employed (807).

In April, 1918, when the shell-filling programme was reduced, instructions were sent to the factory to close down, and after using up the materials in stock, and cleaning plant, the workers were paid off in the following month.

The estimated outlay on the factory was £198,000, and by March, 1919, the actual expenditure was £185,000.

H.M. Factory, Lytham.[1]

In December, 1916, when efforts were made to increase as much as possible the supply of picric acid, three new national factories were planned to utilise a quantity of the raw material, phenol, which was then available. Each was to be managed by a firm which had already proved a satisfactory contractor, and was to produce 80 tons weekly. An agreement was drawn up with each firm, the main points being identical for all the factories. By this agreement the firm undertook to erect and equip the factory in the shortest possible time in return for a fixed sum (in the case of Lytham, £2,000), to appoint and train the necessary staff and to manage and secure the efficient working of the factory in return for a remuneration calculated at the rate of $\frac{1}{10}$d. for each pound of picric produced, provided that a minimum sum of £2,000 should be paid in any year. The Ministry was responsible for all costs, either of construction or production, and either party could terminate the agreement on one month's notice.

The first of the three factories to be started was at Lytham under the management of Mr. Lance Blythe. It had been intended to build this factory at Blackburn, but owing to the difficulty encountered as to railway facilities, the first site was abandoned in favour of a more convenient site at Lytham. The land was about 21 acres in area, level, and fairly low, but free from any possibility of flooding, was adjacent to the manager's works, and could use the railway sidings constructed between them and the Lancashire and Yorkshire Railway; a good water supply was available, and the site was sufficiently isolated to render very remote the possibility of any danger to local inhabitants, in case of accidents. Possession was taken immediately under the Defence of the Realm Act, and an annual rent was paid to the owner.

Mr. Lance Blythe acted as manager of the factory until November, 1917, when, as his previous undertakings prevented his devoting as much time to Lytham as was necessary to efficient supervision, the factory was placed under the immediate control of the Factories Branch of the Explosives Supply Department.

Construction began towards the end of January, 1917, and was vigorously prosecuted, practically all the buildings, and much of the plant, being erected in April. The plant was laid down to ensure the continuous conversion of 50 tons of phenol per week into picric acid, and was complete in respect to the manufacture of the necessary nitric acid, the concentration of waste sulphuric acid and the neutralisation of the effluent from the works. Production began by 28 July, 1917. The output increased steadily through the summer, from 15 tons weekly early in August to 55 tons in October, and the designed output of 80 tons was reached by 10 November, 1917. At the end of the year, when the programme of picric acid production was reduced, the less economical factories were closed down, and Lytham ceased production in March, 1918.

[1] 74/Lytham/1, 14, 16; (Printed) *Weekly Reports;* Hist. Rec./H/1500/6; Hist. Rec./R/1122.7/6, 1122/45, 400/57. M.W.L.S. 32355/3.

Some difficulty was experienced in obtaining labour, though additional workers were brought in from Preston and Blackpool, a special station being built for the factory. The plans of the factory allowed for the employment of 250 men and 50 women, but by August, 1917, no women were employed. Difficulty was anticipated in obtaining women workers owing to the high wages paid by the cotton mills. The management, whose general feeling was against the employment of women, did not intend to appoint any until they were absolutely obliged and considered the work, except in the drying and packing rooms and on trucking, unsuitable to them. Some girls were at work, however, by November, 1917, and at the end of the year women formed 31·6 per cent. of the total number (358).

The working costs of the factory were comparatively high owing to the relatively large amounts of raw materials consumed. The average cost for raw materials per ton of picric produced was £175 per ton at Lytham as against £147 at Greetland, giving an excess expenditure when the factory was working to its full capacity of roughly £100,000 per annum.

The capital expenditure was estimated in December, 1917, at £180,000 ; the actual capital expenditure by March, 1919, was £166,800.

H.M. Factory, Oldbury.[1]

The first national factory for T.N.T. production was erected at Oldbury early in 1915. It consisted of two main units. The one contained plant for nitric acid and oleum manufacture and acid recovery. The other consisted of installations for storing and treating toluol-benzine and nitrating it through M.N.T. up to T.N.T. and also for making T.N.T. from coal-tar toluol. This unit was placed for safety at a distance of 2,000 ft. from the acid plant, which was adjacent to the works of Messrs. Chance and Hunt, a well-known firm of acid manufacturers. The one site was within 200 yards of Oldbury goods station, the other was adjacent to Langley Green Station on the Great Western Railway. The factory was also served by the Titford Canal. The two sites occupied rather more than 18 acres. From time to time extensions were made for various purposes, *e.g.* for box-making and repairing, the total area finally occupied being over 39 acres.

Messrs. Chance and Hunt had first been approached by the Committee on High Explosives in December, 1914, with a view to extending their output of acids, particularly nitric acid. Work on extending their nitric acid plant began 21 December, 1914. This acid scheme was secondary to a project for erecting a factory to make 50 tons of T.N.T. weekly, negotiations for which began in December. Under an agreement of 11 January, 1915, the Explosives Supply Branch of the War Office undertook the responsibility for the lay-out of this plant, which was to be erected by the firm at the expense of the State. The Department was to operate the T.N.T. factory during a preliminary

[1] C.H.E./2553 ; 74/Q./3 ; 74/C/76, 79 ; 74/H.E./4, 22 ; 74/Oldbury/127 ; 74/H.E.T./234 ; Hist. Rec./R/1500/2, 3, 6 ; Hist. Rec./R/1500/14, p. 107.

experimental period and then to transfer it to the firm, whose property it was to become. The firm was thenceforward to operate the plant and deliver T.N.T. under contract, the basic material M.N.T. being provided by the Department.

This agreement was based on the treatment of 30 tons of M.N.T. weekly, the quantity then available for the purpose. It was superseded almost immediately by an expanded project for making between 700 and 1,000 tons of T.N.T. monthly along the lines of the Research Department's two-stage process, worked out about 19 January, 1915, and from toluol-benzine produced at the Portishead distilleries. Arrangements for removing these distilleries from Rotterdam to Portishead were made with the Asiatic Petroleum Company in January, 1915, and the company also engaged to erect at Oldbury plant for treating the toluol-benzine and converting it into M.N.T. When this plant had been brought to efficiency, it was transferred to the Department's representative and became an essential unit of the Oldbury factory.

The lay-out and erection of the T.N.T. factory were controlled by Mr. K. B. Quinan, General Manager of the Cape Explosives Company, whose services were lent by the De Beers Consolidated Mines Company. Mr. Quinan was summoned from South Africa on 18 December, 1914, for this purpose, and arrived in England on 5 January, 1915. Work on the T.N.T. site began on 8 January, 1915, and was carried out with great expedition. The M.N.T. plant was completed by the end of May, and the T.N.T. plant started production in that month. Pending construction a new agreement was negotiated with Messrs. Chance and Hunt, which resulted in the establishment of the nitric acid, M.N.T. and T.N.T. works, together with the oleum plant, as a national factory under the control of the firm as agents of the Crown. The details of the new contract were not settled until the end of April, 1915, but its terms were retrospective as from 1 February. It provided that the Department should be responsible for the lay-out and erection of the installations, the agents assisting in providing labour and materials, etc.; that plant should be installed at state cost and should remain the property of the State; that the sites should be leased by the firm to the Department with certain options as to purchase, and that the agents should operate the factory at Government expense, assisting the Department in the purchase of materials other than toluol, toluol-benzine, or M.N.T. In addition to certain sums already paid towards the cost of acid extensions under the earlier agreement, the firm received a fixed weekly payment during the period of erection and thereafter a weekly payment per lb. of T.N.T. produced, the scale of payment decreasing with certain increases in output. Manufacture was to be from sulphuric acid produced at the firm's neighbouring works and purchased at market prices based on the cost of sulphur. Certain minimum quantities of nitric acid were also to be purchased from the firm's neighbouring works at prices based on the cost of sodium nitrate. Under the new agreement, the oleum plant was erected on the acid site rented by the Department and not within the firm's works, as had been the original intention. Small-scale output began in May,

and from the end of July, 1915, over 50 tons of T.N.T. was produced weekly, and in November, 1915, the factory reached its full output of 130 tons weekly. Much valuable research work was done in the laboratories, where a new continuous process was evolved. This method was introduced into the factory in October, 1917, and enabled the original installation to increase its output five-fold with only slight structural alterations.

The number of operatives engaged in the factory in August, 1917, was 1,749, and in October, 1918, 2,116. The percentage of women employed in both sections increased gradually, was greatest in the T.N.T. section, and was always considerably below 50 per cent., the figure in October, 1918, being 36·7.

The capital expenditure down to March, 1919, was £835,300, of which £60,000 had been the estimated cost of the alterations for installing the new process in October, 1917.

H.M. Factory, Pembrey.[1]

This factory, situated on the Pembrey Sand Burrows, near the village of Pembrey, in Carmarthenshire, covered an area of about 760 acres and comprised over 400 working buildings for the production of T.N.T., tetryl, cordite, and ballistite. The Great Western Railway main line from Paddington to Fishguard ran within three-quarters of a mile of the factory, with which it was connected by two branch lines. A private road, 15 ft. wide, afforded facilities for motor transport to the main Swansea to Carmarthen road. In October, 1914, Nobel's Explosives Company, Ltd., of Glasgow, agreed with the Secretary of State for War to erect and manage a T.N.T. factory at Pembrey, upon the site where they had intended to set up works for making industrial explosives. By the contract drafted in February, 1915, the State was to supply toluol free of charge, and to pay seven-tenths of the capital expenditure; the entire output was to be delivered to the Explosives Loading Company's filling factory at Pembrey. The firm was also under agreement to manufacture at Pembrey propellant explosives for the Admiralty, and in October, 1915, the two agreements were amalgamated and transferred to the Ministry of Munitions. It was then agreed that the State should bear the whole cost of the plant, which should remain Government property after the war, and that after 31 December, 1916, the factory should be operated by Messrs. Nobel on behalf of the Ministry. Supervision was accordingly transferred to the Factories Branch of the Explosives Supply Department on 1 January, 1917, and Messrs. Nobel were retained as agent managers. The original agreement stipulated for the production of T.N.T. and the erection of the necessary acid plant. The work of construction proceeded immediately, and T.N.T. manufacture began in July, 1915. In this same month the Admiralty finally arranged with Messrs. Nobels to erect additional plant at Pembrey for the manufacture of M.D. cordite paste from guncotton supplied from outside sources. The work was put in hand in September, 1915, and the unit was completed by January, 1916, when the production

[1] X235/39; X236/34; 74/N./45; 74/N./61; 74/Pembrey/116: C.R. 2913.

of cordite paste began. A further extension for the production of propellants was effected at the instigation of the Ministry of Munitions, and in October, 1915, the plant was installed for the manufacture of ordnance cordite, rifle cordite, and ballistite. These extensions included sections for the production of guncotton and nitro-glycerine, and extensive additions to the water, steam-power and general service supplies of the factory, which by March, 1916, was producing ballistite and rifle cordite, and by May ordnance cordite. The tetryl plant which had been erected in the autumn of 1915 was in operation by the end of that year. The buildings were arranged in progressive order, raw materials, stores and acid plants being convenient for railway facilities. A safety zone of about 400 yards lay between the T.N.T. and propellant explosives section, and was kept free from buildings.

The factory was originally intended to produce 60 tons of crystallized T.N.T. per week, but later crystallization was abandoned, and the plant altered to produce crude T.N.T. at the rate of 200 tons per week. A further extension increased the capacity to 300 tons weekly. The output of M.D. cordite paste was 200 tons weekly. The propellant section was first planned for the production of 150 tons of ordnance cordite, 40 tons of rifle cordite, and 15 tons of ballistite per week. A further extension of the ordnance cordite plant increased the capacity to 225 tons per week, and when the workers were trained the output rose to 300 tons weekly; but the acid plant was not capable of keeping both the T.N.T. and the cordite plants supplied when they were working to their full capacity.

No public services being available, the factory had to be self-contained and plant was established for supplying water, electric light, power and steam. The water supply was obtained from two small rivers five miles away; intake ponds were constructed, from which the water was carried in 15 in. mains to a low-level pond in the factory, where it was chemically treated, filtered, and pumped to high-level storage tanks, from whence mains were carried throughout the factory. The daily consumption of water was approximately 4,000,000 gallons. Steam was generated at four boiler stations having 33 boilers, capable of producing 5,000,000 lbs. of steam per day. Electric light and power were generated at the factory power station, where seven generators with a total capacity of 4,300 k.w. were installed.

The supply of local labour being insufficient, the majority of the operatives were drawn from Llanelly, and later from Carmarthen and Swansea. They were conveyed to the factory gates by special trains free of charge. All workers were paid at an hourly rate, according to the class of employment. Female labour was introduced into all departments—in acids 10 per cent., T.N.T. 80 per cent., cordite 76 per cent., guncotton 95 per cent., and general labour 30 per cent. The total number of employees in October, 1918, was 4,765, of whom 58·6 per cent. were women.

The site was held on a lease of 99 years at a yearly rental of £1,800. On 28 June, 1917, the Treasury sanctioned an expenditure of £2,600,000, and the actual expenditure to March, 1919, was £2,850,600.

H.M. Factory, Penrhyn Deudraeth.[1]

This factory, situated on the Welsh coast, a quarter of a mile from the goods station, covered an area of 11 acres. It was built by the Ergite Company under a contract to supply T.N.T. to the Admiralty, who bore a considerable part of the cost. In June, 1915, the crystallizing station, workshops, office, laboratory and acid mixing section of the nitration plant were destroyed by explosion, and the Explosives Supply Department undertook to reconstruct the premises as a Government factory, appointing a construction manager for this purpose. No compensation was to be paid to the Ergite Company, but settlement was to be made when plant was handed back. The factory was laid out for the second continuous process of crude T.N.T. production, and was the only one where this process was actually worked, the waste acids being discharged into the sea. In 1917 an important change in the process was adopted, based on the desirability of utilizing still residues after T.N.T. purification. The necessary plant was erected, and it was hoped to recover an amount of T.N.T. equal to 50 per cent. of the total residues so treated, by washing with sodium nitrate; previously these residues had been burnt.

The intended output in December, 1915, was 30 tons per week; the actual output during the month of February, 1916, was 63 tons, during December 148 tons, and in March, 1917, six tons daily. This last average was subsequently maintained. In 1916-17 the labour employed was principally male, the average number being 335 weekly. In October, 1918, of 349 employees 21·5 per cent. were women.

The Treasury sanctioned an expenditure of £67,000 upon this factory on 28 June, 1917. The actual outlay, including the cost of additional plant to increase output, amounted to £83,000 by 31 March, 1919.

H.M. Factory, Queen's Ferry with Sandycroft (Chester).[2]

H.M. Factory, Queen's Ferry, stands on 298 acres of land on the main London and North Western Railway line, from Chester to Holyhead, at a distance of about eight miles from Chester. The River Dee borders it on the northeast. The lease of part of the land was purchased under agreement, and the remainder was taken over under the Defence of the Realm Act. The original scheme provided only for the manufacture of guncotton, an acids section being included to render the factory self-contained. The functions of the factory were, however, increased, and T.N.T. and tetryl sections were eventually added, and also a Grillo oleum section, which made it possible to provide acid for export in addition to supplying the factory requirements. The areas of the various sites were as follows:—Guncotton section, 37 acres; T.N.T. acids, T.N.T. and tetryl sections, 99 acres; Grillo oleum section, 42 acres; M.N.T. section, 120 acres.

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[1] HIST. REC./H/900/9; 74/H.E.T./166.
[2] HIST. REC./H/1122.7/1, 1122.7/10; HIST. REC./R/1122.7/5,1122.7/15.

The factory owed its origin to the anxiety felt by the Admiralty at the beginning of 1915 as to the supply of cordite. The derelict engineering works of Messrs. Williams and Robinson at Queen's Ferry were secured on behalf of the Admiralty at the end of March, 1915, as being readily adaptable for the manufacture of guncotton. The original intention was that the factory should be controlled by the High Explosives Branch of the War Department and its output of guncotton sent for conversion into cordite at the new State factory, then being erected by the Admiralty at Poole. At first plans were made for an output of 100 tons of guncotton per week, but this was later increased to 200 tons. It was not possible to obtain full and immediate possession of the site in order to press on with the adaptation of the works, as German prisoners interned in the buildings were not removed until 14 May. At the end of that month the Admiralty, in order to increase its autonomy in regard to propellant supply, notified that the output from Queen's Ferry would not be needed for naval purposes. The factory was thereupon accepted by the Secretary of State for War for the use of the Army and was transferred to the Minister of Munitions at the end of June. Since the guncotton it was to produce could not be used until the nitro-glycerine and cordite factories, then under discussion, were planned and erected, it became unnecessary to force the speed of construction, and part of the energy available was diverted to the erection of T.N.T. and tetryl sections, the construction of which was decided upon to meet the extended shell programme of July, 1915. In conjunction with this extension the Asiatic Petroleum Company proceeded to build a factory for the production of M.N.T. at Sandycroft on a site lying at the south-east end of the T.N.T. section. This factory was subsequently (in June, 1918) incorporated with H.M. Factory, Queen's Ferry, under the designation of the M.N.T. section. Simultaneously with the drafting of the designs of the T.N.T. and tetryl sections, plans were prepared for a Grillo oleum section. In August, 1915, it was decided also to produce dinitrobenzine, but this project was later abandoned.

The designing, purchasing and erection of the plant was in the charge of Mr. K. B. Quinan of the Explosives Supply Department. The actual construction work was undertaken by contractors, the agreements being of the cost plus percentage type. This form of agreement was necessitated by the fact that the details of the lay-out were settled during construction. The factory was directly controlled by the Factories Branch of the Explosives Supply Department. It was put under the management of a superintendent.

The work of reconstruction on the guncotton section and of construction on the guncotton acids section and boiler house was begun in May, 1915. As soon as sufficient plant was installed, manufacture was begun and finally, on Christmas Day, 1915, the first batch of wet guncotton was packed and ready for dispatch.

Construction on the T.N.T. acids section was begun in September, 1915, the Mannheim oleum buildings being the first to be proceeded with. The first unit of this plant was producing in January, 1916. The first T.N.T. unit was producing by 21 March, 1916, and thereafter

unit after unit of the T.N.T. and T.N.T. acids sections was brought successively into operation until in the month of October, 1916, all the T.N.T. units—5 in number—were operating.

The construction of the tetryl section was commenced in October, 1915, at a time when the supply of tetryl was very limited. The original intention, therefore, was to push on with construction as rapidly as possible, and to complete the plant by the end of January, 1916. The immediate need having disappeared, owing to changes in design of detonating apparatus for H.E. shell, the work of construction proceeded more slowly and was not completed until the end of May, 1916. At first the plant was mainly employed for the investigation of various points of importance in the manufacture of picric acid, and it was not until November, 1916, that the production of tetryl was commenced.

Construction on the Grillo oleum site was begun in December, 1915, the first unit coming into operation in September, 1916. The last of the ten independent units came into operation in May, 1917.

On the M.N.T. section, construction work under the Asiatic Petroleum Company was begun in August, 1915, and production commenced in January, 1916. The principal units of this section were completed six months later.

The output of the guncotton section was for the first seven months of its running service guncotton, and during this period a total of 2,163 tons was manufactured. In August, 1916, a change was made to the manufacture of the lower nitrated form of nitrocotton required for the production of R.D.B. cordite at Gretna. From that time until March, 1918, when the plant was closed down owing to a change in the explosives programme, a total output was achieved of 15,907 tons of nitro-cellulose. The capacity of the plant towards the end of its period of working was about 250 tons a week, these figures being on a dry basis.

The M.N.T. plant consisted of three distinct units, each with an approximate capacity of about 450 tons per week, two of them being designed for working on toluol benzine while the third was specially adapted for the nitration of pure toluol. During the period of operation of the plant over 37,000 tons of M.N.T. were produced for consumption on the T.N.T. plant.

The T.N.T. plant consisted of five units, each consisting of nitration, and washing, drying and packing houses. Each nitration house could be reckoned as having a capacity of 150 tons of T.N.T. per week. Most of the T.N.T. produced at Queen's Ferry was Grade III, but out of the five wash houses, one was fitted, in January, 1918, with the plant necessary for purifying by the sulphite process crude T.N.T. of high setting-point, with a view to obtaining Grade II T.N.T. This process was later modified to permit of the production of Grade I T.N.T. A second wash house was later converted to sulphite process. The capacity of each sulphite house was about 180 tons per week, and of each of the other wash houses 200 tons per week. When the erection of the T.N.T. section was first under discussion, the proposal was for an output of 200 tons per week, but in designing the plant considerable

margin was allowed as regards capacity, and ultimately Queen's Ferry became the biggest T.N.T. producer in the country, reaching a maximum output in 1918 of over 700 tons per week. During the two and three quarters years of operation the total T.N.T. production was 115 tons of Grade I, 5,572 tons of Grade II, and approximately 50,000 tons of Grade III.

The manufacture of tetryl was commenced in November, 1916, the total output, reckoned as crude, being about 460 tons. Nitration was started before the purification plant was ready in order to test the plant and to augment the supplies of crude tetryl. The purification of crude tetryl by means of acetone was introduced in September, 1917, and after the destruction of the Waltham Abbey plant the Queen's Ferry plant was put on full output and became the sole source of supply of Grade I tetryl, the total output being 160 tons. In order to set free acetone for other purposes nitric acid was suggested as a substitute in tetryl purification, and large scale experimental work was carried out at Queen's Ferry. As a result, the nitric acid purification scheme was brought into operation in June, 1918, and in all produced about 214 tons of Grade Ia tetryl. The final capacity of the plant was 25,000 lbs. of purified tetryl per week.

The Acids Section supplied the acids necessary for nitro-cellulose, T.N.T. and tetryl manufacture. It comprised nitric acid retorts, denitrating columns and stills for dealing with spent acid, Gaillard towers, cascades and Gilchrist concentrators, acid mixing plants and Mannheim and Grillo oleum plants. Of these last, the Grillo plant proved easily capable of supplying all the requirements of the factory, and after its completion the Mannheim plant, which in early days was the sole internal source of SO_3 available for the factory, was only kept in operation when the urgent need of oleum for export to other factories necessitated it. The Grillo plant was capable of producing 1,500 tons of SO_3 per week, its total output being about 106,000 tons. The Mannheim plant had a capacity of 420 tons SO_3 per week with a total output of 19,700 tons.

Besides these main products, H.M. Factory Queen's Ferry also supplied a small quantity of trivelene (2–4 di-nitro-toluene) for which there was a demand early in 1918, a unit of the M.N.T. section originally intended for the nitration of D.N.B. being adapted for its manufacture. Shortly before the signing of the Armistice work began upon certain chemical mixtures. Experimental work was also carried out on the manufacture of T.N.T. X, with a view to establishing a satisfactory method of utilizing the stocks of xylene in the country, and also on the manufacture of chlor-sulphonic acid.

The factory was situated in a non-industrial district, but workers were drawn from the surrounding districts, transport being provided by means of trains and motor charabancs. A small township of about 160 houses was built close to the factory at Mancot to accommodate such staff and workers as it was essential to have close at hand. A small hospital for factory patients was included in this township. The Mancot township was erected by the Explosives Department

after an unsuccessful attempt to arrange a scheme with the Rural District Council. It was administered by the factory authorities. Female labour was employed from the very early days, women process workers being engaged in December, 1915. At first some doubt was felt as to the uses to which women could be put in an explosives factory, but ultimately about 70 per cent. of the workers on the chemical processes were women. At the period of maximum output the total number of factory employees was 7,325. In October, 1918, there were 3,749 workpeople, of whom 42·2 per cent. were women.

The total capital expenditure upon the two factories, viz., Queen's Ferry and Sandycroft, down to 31 March, 1918, was £4,046,300.

H.M. Factory, Rainham.[1]

The Rainham Chemical Works, situated on an island wharf on the bank of the Thames opposite to Woolwich, were taken over from the Synthetic Products Company by the War Department under the Defence of the Realm Act, on 28 November, 1914, the day after the Act became law. The situation of the factory subsequently rendered the work liable to interruption from air raids and warnings. Messrs. Coley and Wilbraham, who had installed the existing plant for the manufacture of butyl alcohol, were put in control of the factory and took up immediate occupation, under an agency agreement terminable at one month's notice. They were to convert the plant at state cost into a factory for purifying crude T.N.T., to be provided by the Department, at a fixed price of £5 per ton, and at the rate of 12 to 25 tons weekly as required. The conversion of the plant, which already included large enamel tanks then unobtainable in England, began on 3 December, 1914; the unit for crystallization was completed on 21 December and the first consignment of crude T.N.T. was received on 30 December. Previous to this the alcohol recovering tower was blown down in a gale.

The factory was first planned for the crystallization of T.N.T. from hot alcohol, but experiments with cold alcohol washing were initiated in January, 1915. Output from this process was unsatisfactory, as in addition to serious loss of alcohol, which the firm attributed to the rapidity with which the plant had been adapted, it caused corrosion in the stills. The output from the plant was far below expectation, being only 7 tons weekly, and the financial position of the agents was unsatisfactory. Accordingly in May, 1915, the administration was taken over by the Explosives Branch (then under the War Department) by agreement with the agents. Additional power plant, water supply and vacuum dryers for the recovery of alcohol, which had previously gone to waste, were installed between June and October, 1915, and further extensions including magazines, fire appliances, improved safety arrangements, and a new plant for the recovery of T.N.T. from waste amatol, were carried out between June, 1916, and May, 1917. By September, 1917, the average output of Grade I T.N.T.

[1] 74/C./39; 74/Fac./119; C.R. 2913; 31st Report of Standing Committee on Causes of Explosions.

was 60 tons per week, but owing to the demand for Grade II T.N.T. the greater part of the plant was given over to this product, and a considerable increase of output resulted.

On 13 February, 1918, a fire followed by explosion broke out in one of the vacuum stores for drying T.N.T. recovered from waste amatol, and the factory was almost completely destroyed. The fire service was under repair at the time, and the congested condition of the factory which had been built before T.N.T. was an explosive under the Act, added to the extent of the disaster, although the amount of T.N.T. present had been reduced to a minimum.

The employees in January, 1918, numbered 387. No women were employed.

The total expenditure on the factory shortly before its destruction was £35,000.

H.M. Factory, Sutton Oak (St. Helens).[1]

In February, 1915, the United Kingdom Chemical Products Company bought works, which were on the market, at Sutton Oak, near St. Helens, with a view to erecting plant there for the manufacture of synthetic phenol for the Government. The area of the land was a little over 16 acres. On 1 April, 1915, a contract was signed by which the Government undertook to pay the cost of installation of plant up to a specified maximum, to pay rent for the land during the currency of the agreement and to supply certain of the raw materials at agreed prices. The Government might, on further payment, instruct the company to double the plant capacity. The phenol supplied was to be at a fixed price. On 20 July, 1915, an additional contract was signed for benzol purification. The pure benzol produced was to be used for making the phenol under the previous contract. The method of manufacture was synthesis from benzene through benzene sulphonic acid and sodium salt.

There was considerable delay in the construction of the works. In October, 1915, a fresh agreement was signed cancelling the previous contracts. By it the factory became a government controlled factory, under the Explosives Supply Department. On 20 April, 1916, the United Kingdom Company was given notice terminating the contract, since the working and output of the factory were not considered satisfactory, and on 18 May, 1916, they were formally notified that possession of the works had been taken under the Defence of the Realm Act. Direct control of the works had actually been taken previous to this on 1 January, 1916, when the factory was put under the management of a superintendent appointed by the Department. Purchase of the company's shares was agreed upon in April, 1917.

The area of the buildings was 82,811 sq. ft. The original undertaking was to provide three tons of phenol a day—the company expecting to be able to produce one ton a day in two months' time and three tons a day a month later. In August 1915, the company was instructed to double the plant. Production began in November, 1915,

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[1] Hist. Rec./H/1122.7/17.

the output at the end of that month being at the rate of one ton a day. In March, 1917, the output was 112 tons per month of 4 weeks, *i.e.*, an average of 4 tons a day. Between May, 1916, and 2 March, 1918, the total output was 1,700 tons. The production of phenol ceased in March, 1918, owing to the modification of the explosives programme, whereby picric acid lost its important position. The factory was, however, adapted for the production of some of the arsenic compounds required in 1918 for chemical warfare, chemical plant (autoclaves, etc.) being commandeered for the purpose. Chemical production began about November, 1918.

Owing to the nature of the work it was found necessary to make special holiday and sick pay arrangements for workers on chemicals. A fortnight's holiday was given after every six weeks of work in order to eliminate the arsenic from the system. The numbers employed in October, 1918, were 260, the percentage of women being 19·2.

The total estimated cost was £114,000. The actual expenditure down to 31 March, 1918, was £100,700.

H.M. Factory, Swindon (Stratton Works).[1]

At the close of 1916 it was proposed to take over land under the Defence of the Realm Act for the erection of a government ammonium nitrate factory at Swindon. The first land was taken in December, 1916, and more in February and May, 1917. The factory was erected on 67 acres, a mile and a half from Swindon Great Western Railway station. Construction began early in 1917, and output, with only a part of the plant completed, in September, 1917. In October, 1917, since output had been found to vary considerably according to temperature and the largest requirements were expected to be in the four hot months of the summer of 1918, it was decided to carry out extensions. The total area of the buildings erected was 340,087 ft. From the first, the factory was directly controlled by the Explosives Supply Department, being first under the Ammonium Nitrate Section, and later, from October, 1917, under the Factories Branch. It was managed by a superintendent. The "sulphate" process used was developed by Messrs. Brunner, Mond & Company.

The factory never had an opportunity to go "all out" but it could have produced 1,600 tons per week. As the continuous "sulphate" process used was a new one, and as the factory started up with only a part of the plant completed, production was at first restricted. Output was regulated in accordance with the ammonium nitrate requirements, and was limited during the greater part of 1918 to 500 tons per week. In September, 1918, instructions were given for a production of 1,000 tons per week, and when the Armistice was concluded preparations were being made for a production of 1,500 tons per week. The total output from start to finish was 25,050 tons. As regards cost of production, the "sulphate" process as used at Swindon proved considerably cheaper than the calcium nitrate process as used elsewhere, while it did not compare unfavourably with the ammonia soda process.

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[1] HIST. REC./H/1122.7/3; 74/Swindon/97, 135.

The whole of the labour for the factory, male and female, was drawn from the locality, with the exception of a few skilled workers. It was not necessary for the Government to provide either housing or transport for the workers, as accommodation was available in the town near by. The supply of labour was difficult in as much as the factory was among the last to start up, so that only low-grade and elderly men were available, while the female labour had to be drawn from domestic rather than industrial sources. In October, 1918, there were 1,246 employees, of whom 37·8 per cent. were women.

The total capital expenditure up to 31 March, 1919, amounted to £927,600.

H.M. Factory, Trafford Park (Manchester).[1]

A government refinery for the commercial toluol supplied by Messrs. Hardman and Holden, contractors, was built at Trafford Park, Barton, Manchester, on 8,400 sq. yds. of land. The Government held the land under agreement made with Trafford Park Estates, Ltd., with the option to purchase the freehold within 21 years. Contracts were drawn up with Messrs. Hardman and Holden both for erecting and working the factory. Construction began in October, 1915, and the factory was in working order in July, 1916. The area of the buildings was 17,216 sq. ft. The factory was operated by Messrs. Hardman and Holden, at a flat rate based on the output, a superintendent being in charge.

It was originally intended that the distillery should produce 20,000 gallons of pure toluol per week. By January, 1918, the output had reached considerably more than 40,000 gallons per week. The total production was 3,089,213 gallons of pure toluol and 315,400 gallons of solvent naphtha between the commencement and November, 1918, 457,608 gallons of pure benzol between the commencement and September, 1918, and 71,196 gallons of standard benzol between August, 1918, and November, 1918. There were very few employees, the number in October, 1918, being 27. Of these, 9 (33·3 per cent.) were women.

The estimated total capital expenditure was £33,383. The actual capital expenditure up to 31 March, 1919, was £37,400.

H.M. Factory, Victoria (Northwich).[2]

The site of H.M. Factory, Victoria, was about 50 acres of land situated 2½ miles from Northwich and 2 miles from Lostock, and with this latter place it was connected by the Trent and Mersey Canal. The original site was that of salt works belonging to the Salt Union, Ltd., and the land and existing buildings were rented from this company at a rent of £750 per annum for the duration of the war plus six months, at the end of which time the Ministry had an option to purchase the site, and the Salt Union, Ltd., to purchase the buildings erected by the Ministry. Additional land was taken under the Defence of the Realm Act and further buildings erected. The total area of the buildings was 461,802 sq. ft.

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[1] 74/T/1, 30, 44, 54, 78; 74/H/819. [2] Hist. Rec./H/1122.7/5; 1520/14.

The factory was one of a group of units for ammonium nitrate manufacture in and about Northwich. The other members of the group began operation at various dates by diverse processes and were worked by contractors; Lostock and Sandbach by Messrs. Brunner, Mond, Plumbly by the Ammonia Soda Company, Fleetwood by the United Alkali Company. The Victoria Works were laid out for the production of calcium nitrate tetrahydrate in connection with the programme of January, 1916, for extending the production of ammonium nitrate. Throughout, Messrs. Brunner, Mond acted as technical advisers and general supervisors, but the Salt Union, Ltd., were responsible for the construction, operation and maintenance of the plant, acting as agents for the Minister until October, 1917, when the agreement with the company was terminated as this method of management had not worked smoothly. The factory was accordingly brought under the direct control of headquarters, being first under the Ammonium Nitrate Section and then under the Factories Branch.

By an agreement signed on 30 October, 1916, the Salt Union received 5 per cent. on the expenditure incurred on erecting and equipping the works, and a remuneration of 2s. 6d. per ton of calcium nitrate produced, with a guaranteed minimum of £2,000 and a maximum of £10,000 a year. Construction was begun in February to the designs of Messrs. Brunner, Mond, who acted as consulting engineers. Use was made of certain plant in existence at the Victoria Works and additional plant was brought in from other works; but it was necessary to reconstruct the whole of the buildings and to erect others. The factory was originally planned for a capacity of 1,500 tons per week, but in the autumn of 1916, extensions (originally intended to be a part of H.M. Factory, Albert) were made and these increased the weekly capacity by another 560 tons. Construction continued side by side with production till October, 1917. Output began in an experimental way in August, 1916; in November, 1916, it had reached 150 tons per week, and in November, 1917, it was 1,700 tons per week. A maximum output of 2,300 tons per week was reached in February, 1918, and the total calcium nitrate tetrahydrate produced exceeded 120,000 tons. The process was based on the reaction between calcium chloride and sodium nitrate, calcium nitrate and sodium chloride being formed. The calcium chloride, a by-product in the manufacture of bicarbonate of soda, was drawn from Lostock. The calcium nitrate tetrahydrate crystals produced at the Victoria Works were shipped by canal to Lostock for conversion into ammonium nitrate.

In October, 1916, sanction was given to a plan for erecting alongside the Victoria Works a second factory, the Albert Works, to make calcium chloride for conversion into ammonium nitrate at Fleetwood. Land was taken, but construction was restricted to the installation of 28 pans, which were connected up with the Victoria Works and operated as an extension of them. This change of plan took place towards the end of December, 1916, when a one-stage process for ammonium nitrate production had been worked out by Messrs. Brunner, Mond and decision taken to erect the Swindon Factory for manufacture by this method.[1]

[1] *See* above p. 77.

When work on the Victoria factory began, labour was exceedingly scarce as other large undertakings in the neighbourhood had absorbed many workers, and great difficulties were experienced in obtaining an adequate supply, recourse being had to military labour parties during the early part of 1917. At this time production was hampered by this lack of labour. Until May, 1917, only male labour was employed and it was not until the earlier constructional difficulties were overcome and production was reaching about 100 tons per day that female labour was employed. In October, 1917, at a time when the weekly output was 1,750 tons, the total number of employees was 2,423, of whom 41 per cent. were women. A year later the total number was 1,121, and the percentage of women 34·4. As housing accommodation was very limited, hostels to hold about 1,000 men were brought from Sheffield, where they had been found to exceed the needs of the locality[1]; and special trains were run to bring workers from neighbouring towns.

The total capital expenditure up to 31 March, 1919, was £608,300.

H.M. Factory, Watford.[2]

In the summer of 1915, the Explosives Department of the Ministry decided to supplement the supplies drawn from trade factories by erecting a State factory for the production of ammonal at the rate of 1,000 tons per month, primarily to supply the needs of the Russian Government and also to provide against the probable acceptance of this explosive in the future by the British services. The selection of a suitable site presented considerable difficulty, as it would be necessary to detonate sample charges at the factory at frequent intervals throughout the day, but in August, 1915, 61 acres of agricultural land two miles from Watford Junction were taken over under the Defence of the Realm Act, and the factory subsequently provided explosives for the Trench Warfare Filling Factories erected on the adjoining land.

On 19 July, 1915, the Department entered into two agreements for the erection, equipment and future operation of the ammonal factory. By one of these, Messrs. James Gordon & Company, a firm of engineers and contractors who had made special study of ammonal plant, were entrusted with the entire work of laying out and constructing the factory and supervising the erection of plant, for which they were to receive a commission of 6 per cent. on capital expenditure. The second agreement was made with Messrs. Roburite & Ammonal, the established makers of ammonal, and provided that, in consideration of a royalty of £1 per ton of ammonal produced, the firm should give full information and advice to assist in the construction, undertake the responsibility for the technical management and process of manufacture, maintain a regular inspection of operations and appoint the principal members of the staff, although the latter were directly controlled by, and responsible

[1] *See* Vol. V, Part V, p. 26 *n.*

[2] Hist. Rec./R/1122.7/9; 74/H.E.A./39, 57, 58, 63; M.W. 103, 329. 74/Explosions/69 74/R/302.

to, the Department. All capital expenditure, salaries and working costs were borne by the State.

Construction began at the end of August. Alterations to the plans were made to enable the capacity to be doubled if necessary, but in spite of the changes work was carried on with such despatch that production became possible by December, although the necessary railway sidings were not completed, and additional buildings were added later. During the first weeks of production one incorporating house was brought into operation to produce 10 tons of ammonal daily, and it was also intended to manufacture bellite. The output rose slowly at first, some 2,727 tons of ammonal being delivered by May, 1916, and in June the output for the month was 867 tons, but the factory was also producing smoke powder and ophorite and carrying out experimental work. During the summer a large increase in production was effected and throughout the latter half of the year more than 3,000,000 tons were delivered. A fire occurred in February, 1917, in connection with the manufacture of a French incendiary composition, but the material damage done was not extensive.

Early in 1917 the use of ammonal was abandoned owing to the very great rise in the price of aluminium, and Watford with other factories previously making ammonal changed over to the production of amatol which became the standard high explosive for trench warfare purposes and aerial bombs.

Various methods of effecting the thorough mixing of T.N.T. and ammonium nitrate necessary for the production of amatol were in use by different factories. At Watford, liquid T.N.T. and solid ammonium nitrate were put, in the proportion of 20/80, into a Hind and Lund mixer which consisted of a cylindrical steam-heated box with a spiral stirrer. After being stirred the mixture was transferred to a cold mixer which turned out the amatol as a fine sandy powder. In 1917, the Watford factory was also temporarily engaged in re-treating stocks of sabulite for trench warfare use and in January, 1918, it undertook for a time the preparation of finely powdered T.N.T. for the special mixing plant at Chilwell Filling Factory. Throughout the summer the manufacture of amatol continued and in October the output reached 560 tons weekly of amatol and 88 tons of smoke powder, etc.

In order to secure the labour required for speedy construction workers were paid at London rates which were higher than those prevailing in the district, and little difficulty arose in drawing sufficient labourers. After production began the numbers employed varied between 200 and 400 and the proportion of women and boys ranged at different times from 19 to 28 per cent. of the whole. In October, 1918, the employees numbered 383, and 27·4 per cent. were women.

The estimates of capital expenditure presented in August, 1915, were £17,945 for buildings and £28,600 for plant. As much of the plant was of a new type and production of ammonal had not previously been carried out on so large a scale it was difficult to prepare estimates which were in any degree exact, while subsequent additions were made for new manufactures, *e.g.* ophorite, or proved necessary in view of practical difficulties. Thus the final cost was more than double the estimate,

and Messrs. Gordon's commission was therefore calculated only on the first £50,000. The actual capital expenditure to 31 March, 1919, amounted to £106,800.

H.M. Factory, West Gorton (Manchester).[1]

Messrs. M. N. Morris & Company Ltd., of Gorton Brook, were one of the first manufacturers to put their resources at the disposal of the Government in the autumn of 1914. Their factory, which had been used for the production of aniline, was situated about two miles from the centre of Manchester on eight acres of land. It was in close proximity to Ashbury Station on the Great Central Railway, but had no siding into the works. The surroundings were densely populated, the district being for the most part laid out in small house property. Messrs. M. N. Morris & Company undertook to instal plant at their works for the production of synthetic phenol and M.N.T., the production of the former synthetically having been made necessary by the inadequacy of the supply of coal tar or natural phenol to meet the coming enormous expansion in the production of picric acid. On 6 January, 1915, a contract was made with the firm for 15 tons a week of phenol, and on 12 January for 3 tons a week of M.N.T. Owing to a change in the national programme of production the firm was asked later to turn over from M.N.T. to T.N.T.

Considerable difficulty was experienced with the phenol contract, for the synthetic process was a new one to England and had not been fully worked out here. The method of manufacture was synthesis from benzene through benzene sulphonic acid. There were special reasons connected with textile manufacture for working by way of magnesium benzene sulphonate, as the excess of acid remaining after sulphonation was recovered as Epsom Salt. The chemistry and technical conditions of manufacturing magnesium benzene sulphonate were worked out at Manchester University and a great deal of work in connection with the process was undertaken by the chemists of the South Metropolitan Gas Company. In June, 1915, a representative of the Explosives Supply Department was appointed to the factory to assist Mr. Morris and speed up construction work. The arrangements, however, did not work well. By the end of September, 1915, no phenol had been delivered and only one lot of T.N.T. (subsequently rejected), although by the contract output should have been reached long before that date. On 7 October, therefore, the works were taken over under the Defence of the Realm Act and West Gorton became a government factory.

In August, 1915, owing to the growing demands for picric acid, instructions had been given to double the phenol plant. The plant was finally designed to manufacture 40 tons of phenol per week of 7 days, although only 30 tons per week was guaranteed. The maximum output of phenol reached was an average of 21 tons a week during February, 1917, the total production between October, 1915, and July, 1917, when production ceased, being 1,225 tons. The steady capacity

[1] Hist. Rec./H/1122.7/12.

of the T.N.T. plant was 80 tons per week. The maximum output of T.N.T. reached was 91 tons a week at the end of March, 1917, the total production between October, 1915, and 1917, being 2,900 tons.

Owing to the general arrangements and lay-out of the original factory, and the congested nature of the works, it was exceedingly difficult to render them suitable for producing what was required of them. Risks run in regard to fire and explosions were considerable, and owing to the disastrous effects likely to result from any mishaps of this nature in such a densely populated district, it was decided, early in 1917, to close down the benzol rectifying plant, and in June of the same year the T.N.T. plant was closed down. The manufacture of synthetic phenol by the magnesium process was throughout more or less of an experimental nature, and improvements and alterations in the process were continually being introduced. It proved expensive, and the sale of Epsom Salt produced could never have brought the magnesium process down in respect of cost to the level of the ordinary sodium salt process.

The total number employed in October, 1915, was 395 men. In June, 1916, this number had increased to 863. Labour was not difficult to get, but men were called away to the colours. The employment of female labour was begun in July, 1916. This proved satisfactory, and further female labour was utilized until a maximum of 240 women were employed in the week ending 20 March, 1917, the number of men employed at the same time being 640. In April, 1917, the maximum number of employees was reached, 992, of whom 24·1 per cent. were women. In October, 1918, there were only 72 employees, 5 of whom (6·9 per cent.) were women. Most of the employees were resident within walking distance of the factory, and for those living at a distance, trams and railways provided ample facilities.

The total capital expenditure down to 31 March, 1919, was £304,400.

III.—National Wood Distillation Factories and the King's Lynn Acetone Factory.

Wood Distillation Factories.[1]

In 1913, the Office of Woods and Forests had erected one small factory for wood-distillation at Coleford to utilize waste cord-wood from the Forest of Dean. Before the war this was the only wood-distillation factory in England, as it was thought impossible for British firms to compete with those in the great timber-growing countries of the world. Up to the end of 1915, therefore, practically the whole of the acetone required for British explosives, which was most easily obtained from grey acetate of lime produced from wood-distillation, was imported from America. At the time when the Ministry became responsible for supplies, the estimated service requirements were greatly

[1] 74/Factories/16: 95/3/3, 22; HIST. REC./H/1530/1, 6, 9; HIST. REC./R/400/5.

in excess of all the available American supplies, and efforts were made for the development of existing plant in England and the establishment of new factories. Thus, while the greater part of British requirements were still met in America, additional acetone was manufactured from acetate produced by various State wood-distillation factories established at home.

In 1915, new plant was set up at Coleford to produce 400 tons of acetone yearly upon the War Department's guarantee to take the whole output for the next ten years, at a price not exceeding £100 per ton. The Office of Woods was left to conclude its own arrangements for acetate, and erected two factories at Bideford and Dundee, where 1,200 tons of wood were carbonised weekly, producing, with the Coleford plant, most of the 2,000 tons necessary for the 400 tons of acetone. Messrs. Kynochs, Ltd., erected another wood-distillation factory at Longparish, in Hampshire where, after the summer of 1916, the firm produced part of the acetate required to manufacture the 42 tons of acetone which they contracted to deliver each month. In October, 1915, the Coleford factory, with Bideford and Dundee, was taken over entirely by the Ministry, and early in 1917 Kynochs' works also became a national factory.

In May, 1917, the Ministry instituted a centralised organisation for the sale of the by-products from these factories which had formerly been left to the discretion of the individual superintendents.

The plant in operation at Coleford was of German design, and the new factories were fitted up with American plant similar in principle. The capacity of the factories was between 400 and 500 tons of acetate per year, except at Bideford, which could produce 750 tons. The first output of acetone from Coleford was delivered in March, 1916, but during the summer the output was little more than half the estimated eight tons weekly.

In October, 1917, three new factories were planned for wood-distillation at Mid-Lavant (near Chichester), Ludlow and Carmarthen, to utilise the waste wood from felling operations carried on by the Timber Supply Department, and to provide from the by-products the necessary solvents required by aircraft manufacturers, whose demands were greatly increased at this time by the new aircraft programme. Construction of the first two factories began in the spring of 1918, but they had not reached the stage of production in November, 1918. They were completed for disposal, but as work was hardly begun at Carmarthen, the plans there were abandoned. In all the State wood-distillation factories acetate of lime was regarded as the main product, and in the largest factory the value of the by-products, chiefly charcoal, wood-tar and methyl-alcohol, more than covered the cost of the acetate. In the smaller factories, where service charges were proportionately higher, this result was not achieved, but production was carried on at a profit. The State intervention and control of processes resulted in the considerable development of modern scientific methods, while practically the whole production of the factories was used for war purposes. In the autumn of 1918 the employees at Bideford, Coleford, Dundee, and Longparish numbered 600, of whom 160 (27 per cent.)

were women. The capital expenditure on the first four factories, inclusive of Longparish, was £206,100, while an additional £171,100 was expended on the three later projects by March, 1919.

The following is a list of the factories :—

Factory.	Date of Starting or Nationalisation.
Wood Distillation—	
Bideford	1915
Dundee	1915
Longparish (Kynochs)..	1917
Carmarthen	Construction began in 1918, but production was never reached.
Ludlow	
Mid-Lavant	
Wood Distillation and Acetone Production—	
Coleford (Forest of Dean)	1915

The King's Lynn Acetone Factory.[1]

Another method of acetone production had been in operation on a small scale before the war, at an oil-cake factory at King's Lynn, which had been converted by the Synthetic Products Company in 1912, for making acetone from the starch content of potatoes. In April, 1915, the company had undertaken to supply acetone at a price based upon the cost of potatoes. Advances were made towards extending the factory to produce seven tons a week, but the quality of the output was unsatisfactory. In view of this fact, and on account of the financial position of the company, the factory was taken over under the Defence of the Realm Act in March, 1916. Thenceforward it was directly controlled by the Propellants Branch of the Explosives Supply Department.

More satisfactory results were obtained by the Weizmann process for making acetone from maize, which was adopted in June, 1916. During the autumn of 1917, a collection of horse-chestnuts was organised throughout the country in order to provide a substitute for maize. Experimental work in producing acetone from chestnuts began at King's Lynn in April, 1918, but the poor quality of the material hampered output. The initial difficulties of manufacture from the new material had, however, been overcome when the factory was closed down in July, 1918. There were at that date 100 workers employed, 47 of whom were women. The capital expenditure on the factory by March, 1919, was £4,300.

IV. National Cotton-Waste Mills.[2]

In the late summer of 1915, when greatly increased quantities of cotton waste were required, by far the greater part of the supplies

[1] For acetone production in distilleries, *see* Vol. VII, Part IV, Chap. IV.

[2] HIST. REC./H/1530/1, 7, 10; 1500/5/4 ; 95/C/872, 889 ; HIST. REC./R/1122/10, 45 ; X/Labour/490.

of the country was controlled by the British and Foreign Supply Association. In September an assisted contract was placed with the Association to obtain 300 tons weekly for the national cordite factories from January, 1916, the Ministry bearing the cost of the additional mills and machinery required, but in August, 1917, this contract was superseded by an agreement under which the Ministry bought out the Association and acquired the mills, which the former directors continued to manage as agency factories. After some months, in order to give the mills the benefit of the technical and scientific knowledge of the Explosives Supply Department in the matter of the preparation and suitability of cotton waste for explosives, steps were taken to effect a closer control over the operations of the mills. The directors resigned and from May, 1918, each mill was regarded as a separate Government factory and directly controlled by the Propellants Branch. The factories were known as His Majesty's Cotton Waste Mills at Bury, Charlesworth, Greenfield, Hadfield, Oldham, Rawtenstall, Whaleybridge and Woodley. The former head office of the Association at Manchester was retained as the central administrative office for the mills, through which the Ministry exercised financial control and purchased raw material.

When the property of the Association was taken over in 1917, four mills were actually at work—Waterside Mill, Hadfield, which had been newly acquired in 1915; Holme Mill, Rawtenstall; Calrows Mill, Bury, and Greenfield Mill. The mills at Charlesworth had been burnt down and were being rebuilt, and in April, 1918, Holts Mill at Oldham was also closed down. The Greenfield Mill was used in 1917 for experimental purposes in connection with the projected installations for nitro-cellulose powder production, and was closed down from August, 1917, to February, 1918, pending the results of manufacturing trials which were being carried out by Nobel's Explosives Company. In the spring of 1918 it was restaffed and equipped with new machinery at a cost of £1,200, and production began again on more scientific lines. The output was increased from an average of 41 tons weekly in April to 67 in October, and by the date of the Armistice had just reached 100 tons weekly. The quality of the cotton was also improved, and a reduction in cost of £22 per ton was effected in five months. By the end of the summer an additional 124 tons weekly of cotton waste was needed, and arrangements were made to reopen the mills at Whaleybridge on 30 September, and Cloughfold and Constablelee, Rawtenstall on 7 October. In November, 1918, all the mills were instructed to cease production.

The nationalisation of all the mills was followed, as in the case of Greenfield, by a general reorganisation, review of methods and increase of experimental work, which resulted in considerable improvements both in the quality and quantity of the output, while the efficient costing system introduced in several of the mills indicated that the financial results of the change were very satisfactory. The capital expenditure upon the mills down to 31 March, 1919, had amounted to £455,400.

CHAPTER III.

NATIONAL SHELL FACTORIES.

I. Introduction.[1]

(a) The Origin of National Shell Factories.

The National Shell Factory dates its existence from pre-Ministry days, and to Leeds belongs the honour of having provided the archetype.

In the spring of 1915, in response to the need for further methods for increasing munitions output, various local Munitions Committees had organised themselves throughout the country. They represented in the main the smaller engineering firms, many of whom had acted as sub-contractors to the armament firms, but were not themselves equipped for making complete shell. The earliest method of employing the resources of these committees was to form a co-operative group of firms, each of whom could undertake certain processes resulting ultimately in the assembling of the complete shell.

In April, 1915, it was arranged that the Leeds Munitions Committee (who had a co-operative scheme under consideration) should visit Woolwich to see processes.

> "They returned unanimously of the opinion that, in view of the difficulties as to machine tools, supervision, inspection and control the best method in a district was to select a suitable factory and concentrate tools, workmen, supervision, and inspection under one management on a non-profit basis, and while the factory was being equipped to send the management, together with selected skilled workmen to a properly organised ammunition factory for instruction."[2]

This idea of a national factory largely obviated the main weakness of a co-operative scheme, namely the difficulty of providing competent supervision and inspection on an adequate scale, and was accordingly approved by the Armaments Output Committee. On 7 May a draft scheme for the Leeds factory was approved in general outline, and the formal sanction of the Government to a revised form was obtained on the following day.

While the principle of co-operative groups was not abandoned, the establishment of a National Shell Factory was now offered as an alternative to Munitions Committees, to whom its concreteness

[1] Vol. 1, Part III, Chap. IV; D.A.O./Misc./30, 238, 418, 1260; D.A.O./4/524; Hist. Rec./R/1121/46, 47, 48. *Factories and Products Lists.*

[2] Memorandum by Sir Percy Girouard, quoted in Vol. I, Part III, p. 71.

appealed, and by the close of June, 1915, some seventeen factories on the same lines as Leeds were already approved, while many others were projected.

(*b*) *Administration by Boards of Management.*

By the time the Ministry was established, a form of procedure had grown up with regard to local Munitions Committees which then became stereotyped. As soon as the proposals of any committee had been approved at headquarters they were instructed to submit from their numbers nominees for a Board of Management to carry out the proposed scheme. This Board, which was limited to about five persons[1] (generally engineers of standing), and only in one or two isolated cases included labour representatives, had to receive direct sanction from the Minister before it could embark on its work.

Once approved, the Board entered into an agreement with the Ministry, following in all cases the same model—that which was drawn up in May, 1915, between the Leeds Board of Management and the Government. The position of a Board of Management under its agreement may be thus summed up :—

(1) The Board was authorised to rent suitable premises at a rent approved by the Government, whose sanction was also to be obtained for the erection of any new buildings or extensions.

(2) The Board could equip the factory with machinery either by hire or purchase. Any purchase of new machinery was to be referred to the Government, who was to be the owner or lessor of all machinery in use at the factory.

(3) The Board was empowered to engage labour and appoint suitable engineering, administrative and secretarial staffs, and provide necessary staff accommodation. No salary in excess of £500 per annum was to be authorised without the prior approval of the Government.

(4) The Government was to place all necessary funds at the disposal of the Board, and an auditor to the factory was to be appointed by and responsible to the Government.[2]

(5) The Board offered their voluntary services to the Government, from whom they would receive technical advice and supervision. No member would receive any remuneration or profit in his individual capacity, but out-of-pocket expenses would be borne by the Government.

These early agreements gave the Boards of National Shell Factories very wide powers at a time when their local knowledge was of supreme importance, and when the headquarters staff was small in numbers and engaged in solving the problem of its own organisation. Later on, as the central organisation grew stronger, it was possible to exercise a greater control over the Boards, and their powers were to

[1] For the *personnel* of the Boards, *see* Vol. II, Part II, App. IV.

[2] In April, 1917, the work of these auditors was brought into line with the work carried out by the headquarters audit staff at other national factories (D.A.O./Bds./65.)

a considerable extent restricted, though no clauses in the agreements were actually revoked.

Similar methods of management were adopted in the case of the National Filling Factories; but their Boards of Management did not report through the Director of Area Organisation.[1]

All necessary funds for administrative and working expenses were placed at the disposal of the Board. Administrative charges were automatically recovered by charging them to factory costs.

As administrative units the Boards of Management were attached to the department of the Ministry controlled by the Director of Area Organisation, to whom they were directly responsible, and who had ultimately the power to disband them. In order to co-ordinate this work with that of other departments of the Ministry, the D.A.O. Executive Committee was appointed in May and sat until December, 1916, to control all schemes administered by Boards of Management. It included representatives of the departments dealing with finance, supply, labour and contracts, and its functions were carried on in 1917 by the Shell and Components Manufacture Executive Committee, which, in addition to Board of Management schemes, included within its scope the management of National Projectile Factories, thus securing the closest co-operation on every side of a shell factory's work.

As regards the Area Offices set up throughout the country to represent the Ministry, the only officer with whom the management came into very close contact was the Superintending Engineer, for the National Shell Factory unlike the co-operative group was essentially a self-contained scheme. The practice established in July, 1915, of affiliating every National Shell Factory to a "mother" armament firm from whom technical assistance could be received fell, indeed, into abeyance with the appointment of Superintending Engineers, whose duties as technical advisers to all Boards of Management within their areas included the inspection of National Shell Factories, and investigations concerning and transference of available machinery.

For purposes of labour regulation and labour supply a National Shell Factory was classed as a controlled establishment.

(c) *Premises and Equipment.*

The selection of suitable factory premises formed a very important side of the self-imposed work of Boards of Management. Urgency was the essence of their early work, and, save in a few isolated instances (and those of a later date) existing premises were adapted to the purpose of shell-making, and in this way buildings of a totally unexpected character, as for example, an old herring-curing factory, a malt-house, toy factory, a roofed market, a rifle drill-hall, served their turn as National Shell Factories. Railway engine sheds and repairing shops were successfully adapted, and the corporations of various towns also placed premises in their Tramways or Electricity Departments at the disposal of the local Board.

In some instances engineering firms would offer shops in their own works, following in this the initial example of the Leeds Forge Company,

[1] *See* below, p. 149.

who furnished the first site for the Leeds national factories. In these cases the firm was represented on the Board of Management.[1]

In many cases premises were lent, rent free, for the duration of the war while in others a nominal rent only was taken.

The adaptation of premises not primarily intended for engineering purposes had drawbacks; owing to the construction of the buildings, the machines, which composed the plant, had to be laid close together; this congestion, together with low ceilings and narrow gangways, often made it difficult to fit up modern appliances, such as travelling or floor cranes.

A further handicap was often the machinery itself. The earliest efforts of the local committees had everywhere been to prepare some sort of census of surplus machinery in the district available for munition work which, in the case of a National Shell Factory, formed part of its preliminary equipment. Under their agreements with the Ministry, the Boards were empowered to hire or purchase this machinery. The general arrangement for hiring was that a Board paid 1½ per cent. per month on the agreed value of the machine (based on the original cost at the time of hiring)[2]. Some Boards, however, preferred to purchase second-hand machines and avoid later questions of depreciation.

The policy of the Boards was to instal plant as quickly as possible, but the most readily obtainable was not always the most suitable. Every Board was not so fortunate as Dundee, which secured the use of a prize cargo of American engine lathes intended for Germany, and there were many early complaints of hindrances caused by the breakdown of second-hand machinery. The factory at Huddersfield, for instance, was seriously hindered at the outset by its local machinery, practically all of which had to be replaced before the end of 1915. At Bury, on the other hand, the lathes borrowed from various factories and mills in the neighbourhood, supplemented later by a few new Government machines, worked very successfully.

The local hire or purchase of second-hand machinery must be regarded as an early stage in the equipment of factories which, as they expanded their work, or it changed its character, received large additions of new machinery at the Ministry's expense; thus, the Haymarket National Shell Factory, at Liverpool, beginning with a "loan collection" of some sixty machines, had at the time of closing down 350. Some small factories, however, remained stationary; Portmadoc, for example, never exceeded an equipment of twenty-three lathes, of which four only were provided by the Ministry. While it would be both difficult and misleading to find figures to represent the percentage in National Shell Factories of second-hand and new equipment respectively, it is justifiable to state that but for this timely local help the larger factories would have had far greater difficulty in getting to work,[3] while the smaller factories could never have started at all.

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[1] In special cases premises were taken over piecemeal and administered by Boards (*see* Aberdeen, Ailsa Craig, College Park Works, Uskside).

[2] D.A.O./5/22.

[3] It should be noted that where new machinery was in question the National Shell Factories experienced all the delays in deliveries common to factories and contractors generally.

(*d*) *The Supply of Material.*

From the beginning the Ministry arranged directly for the supply of 18-pdr. shell steel to the National Shell Factories. As a general rule, forgings were also supplied in the same way, though in a few exceptional cases Boards were at first allowed to make their own arrangements. Early in 1916, the principle of central purchase of all forgings for National Shell Factories was fixed and was subsequently maintained, except as regards the Liverpool Board, one of whose factories produced the forgings required in their area.[1]

The supply of both shell steel and forgings to Boards of Management was to some extent secured and regulated by monthly allocations made in the Department of Area Organisation, based on reports from the Gun Ammunition Department. The allocation was sent to the Steel Department, which despatched issue warrants to the steel maker for approximately the amount allocated by the Department of Area Organisation, and, although the full quantity was seldom or never available, and deliveries were very irregular, the Boards in this way secured some proportion of their requirements during periods of shortage.

Shell components were at first purchased by the Boards themselves. The prices paid, however, differed so widely and had so much to do with the early high cost of shell, that at the beginning of 1916 a scheme was initiated for the central purchase of all component parts.

An interesting experiment was made by the Boards of National Shell Factories in the Lancashire area. Some time prior to June, 1918, they formed a committee for the co-operative purchase of all stores, which met at the Manchester Area Office, and kept in close touch with the departments dealing with purchases for National Projectile Factories.[2]

(*e*) *Work undertaken by the Factories.*

The exhibition of sample shells arranged in March, 1915, to be held at various centres for the information of intending contractors, had been confined to 18-pdr., 4·5-in., and 6-in. shell and No. 100 fuse; of these, the 4·5-in. and the 18-pdr. shell represented the most urgent need of the War Office at the moment. Mainly for this reason, but partly also because available machinery was best adapted for it, the greater number of National Shell Factories took up the manufacture either of 4·5-in. or 18-pdr. Hence, there arose in the early days of the Ministry, an artificial classification of national factories under which National Shell Factories were supposed to be limited to shell under 6-in., while 6-in. shell and upwards were the work of the National Projectile Factories. How arbitrary is this classification will be seen from the subjoined accounts of factories, for almost every type of shell up to 9·2-in. was subsequently produced in one or other of the National Shell Factories.

Various reasons make it impossible to estimate in round numbers the work of National Shell Factories as a whole. The hindrances likely to arise from unsuitable premises, or antiquated machinery, have been indicated, but there were other causes at work. In the first place,

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[1] *See* below, p. 109. [2] (Printed) *Weekly Report* No. 147, VI A (22.6.18.)

when a Board of Management controlled both a National Shell Factory and a Co-operative Group, it was quite usual for the factory to undertake certain finishing processes for the group with a consequent diversion from its own output. One National Shell Factory indeed (Bristol), confined its work entirely to collecting, banding and varnishing shell produced by the West of England group of contractors. Again, National Shell Factories suffered very severely from the exigencies of the shell programme, and this more particularly in the case of the large number of factories manufacturing 18-pdr. shell, which, owing to the glut of that shell, were turned over in the summer of 1916, to other types of shell, only to be turned back again at the close of the year. Finally, the fact that not only were they national property, but that their administration was more directly under the immediate control of the Ministry than were other national factories, made it possible to turn them over on occasion to the supply of temporary needs, such as the manufacture of proof-shot of all types or the rectification of shell.

Some indication of the extent of the factories' contribution is, however, given by the following table, which shows the total deliveries into bond of the principal types of shell produced. In the majority of cases, the figures taken are those of shell actually manufactured in the factories, and do not include shell finished. The output of the Bristol factory is, however, included, and in some cases, such as Llanelly, rectified shell have also been counted. The output of the Leeds factories[1] is given with that of National Projectile Factories[2] and is not included here, while the figures for Ailsa Craig[3] are inclusive of deliveries after 1 June, 1918, when it became a National Projectile Factory. Details of the output of individual factories are given in Appendix I.

Nature of Shell.	Total Output, 1915.	Total Output, 1916.	Total Output, 1917.	Total Output, 1918.	Grand Total.
13-pdr. H.E.	9,400	324,300	57,100	10,600	401,400
18-pdr. H.E. Chemical and Smoke.	137,600	2,525,200	4,053,300	4,450,200	11,166,300
18-pdr. S.	—	—	—	167,200	167,200
2·75-in. H.E. ..	—	64,800	35,300	—	100,100
S. ..	—	1,300	3,000	—	4,300
3·7-in. H.E.	—	—	140,300	11,900	152,200
6-pdr. A.A.	—	19,100	2,100	—	21,200
4·5-in. H.E. and Chemical.	15,100	876,100	2,269,300	2,353,900	5,514,400
4·7-in. Chemical ..	—	—	3,400	—	3,400
60-pdr. H.E.	—	133,500	305,200	169,100	607,800
6-in. H.E.	1,000	195,500	716,100	812,600	1,725,200
8-in. H.E.	—	14,700	80,300	12,700	107,700
9·2-in. H.E.	—	—	29,400	25,900	55,300
Grand Total ..	163,100	4,154,500	7,694,800	8,014,100	20,026,500

[1] The total output of the Leeds group was :—144,000 4·5-in. ; 992,200 6-in. 13,800 8-in. ; 431,300 9·2-in. ; 6,600 12-in. ; and 7,300 15-in.

[2] *See* below p. 129.

[3] A total of 184,800 4·5-in. H.E.

It is claimed by the Director of Area Organisation that the National Shell Factories represented a great national saving, both directly by economic production, and indirectly by providing information from costings made in the factories which led to a general reduction in the price of shell to contractors. During the experimental stages, it is true, costs were necessarily high but, with one or two exceptions, they were reduced by June, 1916, to, or below, the level at which shell could be purchased from outside contractors.

Examples may be used to illustrate this point:—Liverpool claims to have saved in its four factories (manufacturing types of shell ranging from 18-pdr. to 8-in.) upwards of £841,000, on about £6,598,000, the latter sum representing standard prices of the Ministry. Bury, a small Board hampered by great difficulties, had by August, 1918, reduced the cost of 4·5-in. shell to 20s. 10·04d., considerably lower than the current contract price. Grimsby Board, also much handicapped by obsolete buildings, produced good results with 6-in. shell, bringing the cost in December, 1916, down to 61s. 5d., comparing favourably with the schedule price paid to contractors of £3 8s.

The total capital expenditure on National Shell Factories up to 31 March, 1918, amounted to approximately £2,523,000. This total includes expenditure on those factories which started as National Shell Factories but were later administered by other departments of the Ministry—*i.e.*, the Leeds factories, which became National Ordnance Factories and Ailsa Craig and College Park (Metropolitan Munitions Committee) which became National Projectile Factories. It also includes the Hartlepool factory, which was transferred to the Admiralty at the end of 1917. The figure for Leeds (£779,800) includes the cost of converting plant to gun work at Hunslet and Armley Road. In addition, the Rectification Factory at Bacup, which was not completed by March 1918, had a year later cost about £19,500.

In October, 1918 the employees in 40 factories numbered 18,375, the percentage of women being 6·5. The employees at the following factories are not included in these figures:—Hartlepool, Leeds, Ailsa Craig and College Park and Ebbw Vale (closed down). Labour conditions varied considerably owing to the diverse nature of the work undertaken and the differences in size between the factories. A note of the chief characteristics will be found under the account of each factory.

II. Individual Shell Factories.

The Barnsley National Shell Factories.[1]

No. 1 (*Dominion Works*).—In August, 1915, the Barnsley district, hitherto working in with Rotherham, set up an independent Board of Management, which, on 30 August, was formally authorised to establish a National Shell Factory. Premises were rented in the Dominion Works, Johnson Street, at a rent of £85, afterwards raised to £150.

[1] D.A.O./3/642, 646, 641, 717; HIST. REC./H/1121.23/2, 4.

An output of 500 4·5-in. shells, rising to at least 1,500 a week was offered. First deliveries were made in January, 1916. In 1917, when the factory was turned over to the production of 4·5-in. lachrymatory shell, the capacity was 4,000 a week. In January, 1918, it was decided to transfer the plant of this factory to the newly-established factory at Sackville Street.[1] The factory remained idle until September, 1918, when fresh 4·5-in. plant was installed, and at the time of the Armistice about one-third of it was in operation.[2]

A large number of local machines formed part of the original equipment, which was gradually replaced by new tools.

There was an ample supply of labour; in October, 1917, for example, it was reported that there were 400 names on the waiting list. In December, 1917, 446 people were employed, of whom 82·3 per cent. were women. The capital expenditure to 31 March, 1918, was £51,000.

No. 2. (*Hope Works, Sackville Street*).—In October, 1917, the Barnsley Board of Management offered to undertake a factory for the manufacture of 6-in. shell. The Ministry approved their scheme, which they estimated would take four months to get going. An old weaving shed and offices, known as the Hope Works, Sackville Street, were rented at £50 per annum, with an option of purchase subsequently exercised by the Ministry. Additional premises at £20 per annum were taken in June, 1918.

An output of 1,500 to 2,000 6-in. shells per week was promised, but before manufacture could begin, the scheme had to be abandoned owing to the steel shortage. It was then decided to transfer the 4·5-in. plant from No. 1 National Shell Factory to this factory, which was considered more convenient, and until the Armistice it produced an average of 4,000 shells a week. The total output from this and the No. 1 factory was 304,600. In March, 1918, the employees numbered 467, the percentage of women being 83·3.

The capital expenditure to 31 March, 1918, was £14,500.

Birmingham National Shell Factory.[3]

At the close of April, 1915, the Birmingham Munitions Committee on the recommendation of the War Office began to consider the possibility of establishing a National Shell Factory. Their original idea was to equip a factory for the finishing and assembling of contractors' shell only, but the plan developed and the agreement which was finally signed between the Ministry of Munitions and the Birmingham Board of Management on 14, June, 1915, authorised the Board to manufacture 4·5-in. shell on their own account, while also finishing shell obtained by co-operative methods.

The Board rented as a factory premises belonging to the Midland Railway Company Wagon Works at Washwood Heath and additional

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[1] *See* below No. 2 National Shell Factory.

[2] This factory after its fresh equipment is sometimes called No. 3 National Shell Factory, Barnsley.

[3] Hist. Rec./H/1121.24/6; D.A.O./Misc/1394; D.A.O./4/1058; *Order and Supply Lists*; (Printed) *Weekly Reports, passim.*

premises were rented from January, 1916. A representative of the Company was appointed to the Board in February, 1916.

During the first year of its existence the control exercised by the Birmingham Board over the National Shell Factory was weak, owing partly to the fact that the offices of the Board were at the Council House, Birmingham, some distance away, and that the Board itself was mainly occupied with the work of the co-operative group. As a result, the factory delayed considerably in reaching the productive stage, and was unable to make adequate provision for the reception and inspection of contractors' work. Reforms were effected by the D.A.O. Executive Committee in June, 1916, when the administrative work of the Board was concentrated at the factory and a Secretary to the Board, who was also manager of the factory, was appointed.

The factory extended its original programme considerably, and the work which it undertook may be grouped as follows :—(*a*) The manufacture of 4·5-in. shell; (*b*) the finishing of contractors' shell; (*c*) the manufacture of 9·2-in. shell; (*d*) the manufacture of cartridge cases and copper bands; (*e*) the assembling of fuses; (*f*) the manufacture of gauges.

Under their original agreement the Board undertook to manufacture 5,000 4·5-in. shells a week. Delivery was delayed until February, 1916, but once started, output increased rapidly, and by August, 1916, had attained a maximum weekly output of 14,500 shells. In November, 1916, the Board was instructed to change over to 4·5-in. chemical shell, but in March, 1917, the instruction was cancelled before it had taken effect other than a disorganisation of the 4·5-in. shell shop.

The Board also originally agreed to finish in their factory at least 3,000 18-pdr. shells a week and an indefinite number of 4·5-in. produced by co-operative methods in the Birmingham District. In May, 1916, the manufacture of 18-pdr. shell was ordered to cease here as elsewhere, and on its general resumption in the autumn it was found that the 18-pdr. machinery in the Birmingham factory had been dispersed or absorbed in the manufacture of larger shell. The finishing of 4·5-in. shell continued throughout ; before the close of 1915 contracts representing 10,000 4·5-in. shells a week were placed, and though this section of the factory's work did not get satisfactorily going till after the middle of 1916, a maximum capacity for finishing 12,000 shells a week was subsequently attained.

The total number of 18-pdr. shells manufactured by the factory to the end of 1918 was 57,000, and of 4·5-in. 1,736,300.

Towards the close of 1915, preparations were begun to equip a shop in the factory for the production of 9·2-in. There was considerable delay in installing machinery and shell was not delivered till October, 1916. In 1917 an output of 500 shells a week was attained, increasing in 1918 to 750. The total number manufactured was 49,200. In July, 1918, it was decided to stop production and in November, 1918, preparations were being made to hand the shop back to the company.

In July, 1915, plant was purchased for a cartridge case shop to produce 5,000 4·5-in. cases a week. It was allowed to be idle till well into

1916, when experimental work was begun, but by the beginning of July, only 50 cases were actually completed for inspection. It was then decided that as the supply of cases from other sources was adequate, while there was a greater scarcity of copper bands, the shop should be turned over to the production of the latter component. Owing to the delay in procuring the necessary equipment, 8-in., 6-in., 4·5-in. and 3-in. cartridge cases continued to be manufactured till November, 1916, by which date large numbers of copper bands were being turned out. This department henceforward supplied copper bands sufficient not only for the factory but for the whole district administered by the Birmingham Munitions Committee.

No manufacture of fuses was done in the factory, but a shop was equipped solely for the assembly and rectification of fuses and parts made by contractors to the Board. These operations were taken up early, and already in August, 1915, the Board reported to Mr. Lloyd George that contracts were placed for 5,000 fuses a week, augmented in November to 20,000. The Fuse Gallery was not fully organised till December, 1915, and there was at first a good deal of confusion owing to arrears to be dealt with. The Board also assembled primers, whose parts were severally contracted for by local firms.

The pressing need for gauges determined the Board early in November, 1915, to institute a gauge department of its own. The shop was equipped and in working order by January, 1916, and in April attained an output of 150 gauges of various calibres a week. In process of time this gauge department supplied the requirements of the factory and the co-operative group and also, at need, provided gauges for the Ministry, attaining an output of 400 gauges a week.

The maximum number of employees at the National Shell Factory (in November, 1917) was 2,400, of whom approximately 66 per cent. were women. By October, 1918, the numbers had fallen to 1,774, the percentage of women being then 62·5. There was no systematic Sunday labour but, especially in the early days of 1915–16, a considerable amount of work was performed by volunteers working as labourers and taking pay at ordinary piece-work rates.

The capital expenditure to 31 March, 1918, was £187,600.

Bradford National Shell Factory.[1]

The Bradford Munitions Committee, formed in April, 1915, decided that a factory on the same lines as that established at Leeds was their best method of employing local resources. On 19 May they made an offer to the War Office, and on 31 May were officially authorised to proceed with the scheme.

Part of the Valley Dyeworks Shed was taken on 26 June, 1915, at a rent of £600. On 3 April, 1916, a four-storey building belonging to the same works was sub-let by the Bradford Corporation to the Bradford Board of Management for £519 5*s*. A final addition, part also of the same works, was made to the factory in December, 1916, at a rent of £54 yearly.

[1] D.A.O./3/518, 684, 246.

The Board undertook in its original agreement to produce 2,000 4·5-in. shells weekly. The first lot was bonded in November, 1915, and the factory's total output of finished shell to the end of 1918 was 654,000 4·5-in. H.E. and 23,800 4·5-in. chemical shells, as well as 125,000 bodies of 4·5-in. chemical shell, which were completed by the trade. In addition the Board manufactured 2,734,850 fuses, 1,921,400 gaines and 582,000 adapters. In the manufacture of the fuse the factory co-operated with contractors to the Board, who made a certain number of individual parts.

The early equipment was composed of some 814 lathes lent locally, such new machinery as was indispensable being made in the Bradford district. Its second-hand machinery had to be replaced subsequently by stronger and more suitable plant. In October, 1918, there were 738 employees in the shell department, of whom 74·7 were women and 244 (81·6 per cent. women) in the fuse department.

The capital expenditure to 31 March, 1918, was £56,700.

Bristol National Shell Factory.[1]

On 12 June, 1915, Mr. Lloyd George visited Bristol. He then strongly advocated the establishment of a National Shell Factory in addition to a co-operative scheme. The suggestion was acted on, and on 23 June the West of England Board of Management was authorised by the Army Council to establish a factory.[2]

Premises which would be central for the large and scattered area administered by the Committee had to be found. Works at Bristol, Swindon and Gloucester were examined, and the Castle Ironworks belonging to Messrs. J. Priest and Son, St. Philip's Marsh, Bristol, were eventually rented for £360 per annum.

Conditions in the area were more favourable to co-operative work, and it was decided to use the factory at first as an assembling place for co-operative shell and develop the manufacturing side later. Tools were collected for the latter purpose, but by the beginning of 1916 it became clear that there was little prospect of turning out complete shell, and the factory concentrated wholly on the completion of co-operative shell. The total output of finished shell delivered to bond was 3,033,200 18-pdr. H.E. and 167,200 rectified 18-pdr. shrapnel. The labour employed in October, 1918, numbered 348, the percentage of women being 86·5.

The capital expenditure to 31 March, 1918, was £20,000.

Bury National Shell Factory.[3]

Between June and August, 1915, the Bury Munitions Committee were considering the possibilities of establishing a national factory. A preliminary scheme for the production of 2,000 6-in. shells a week was submitted in August, but the suggested premises were not

[1] HIST. REC./H/1121.26/1 ; D.A.O./Misc./1394 ; HIST. REC./H/1121/5.
[2] Through an oversight ministerial approval was not received till 9 August.
[3] HIST. REC./H/1121.22/8 ; D.A.O./Misc./1394 ; Vol. II, Part II.

considered suitable by the Ministry and the scheme was rejected. In September the offer by the Bury Corporation of a part of their Central Tramway Depot rent free made it possible for Bury to make further proposals, and on 25 September the Ministry entered into an agreement with the Bury Board of Management.

Under this agreement the factory was to produce a small weekly output of 4·5-in. shell working up as quickly as possible to 1,000 weekly. The equipment consisted of ordinary engineering lathes, borrowed from the local mills and factories and fitted with the special equipment necessary for the manufacture of 4·5-in. shell bodies, supplemented by various special tools.

The factory turned out in all 111,900 4·5-in. H.E. shells and 31,500 18-pdr. smoke shell, and in addition undertook the rectification of proof and other shell.

As the factory occupied a central position no difficulty was found in maintaining a good supply of female labour, recruited mainly from the cotton and woollen mills in the neighbourhood, and dilution was maintained on the required scale. In October, 1918, women represented 79·3 of the total number (121).

The capital expenditure involved in the establishment and maintenance of this factory to 31 March, 1918, was £11,700.

Derby National Shell Factory.[1]

On 28 May, 1915, the War Office received a deputation of the Derby Munitions Committee, who came prepared with plans for a National Shell Factory. Consent was given to the scheme, and the committee instructed to appoint a Board which received approval on 15 June.

The site chosen was the Peel Foundry, in Darwen Terrace, a new building belonging to Messrs. Russell and Sons, from whom it was rented at £400 per annum. An additional shed was taken as a bonding store for £15 per annum. The building had to be adapted, and a railway siding was added in 1916.

The factory was controlled by a general manager, who was also Secretary to the Board. It was originally intended to supply 5,000 18-pdr. shells a week, but the Board was almost immediately instructed to make 4·5-in. shell, aiming at a weekly output of 4,000. First deliveries were made in December, 1915, and by August, 1916, a steady output of 6,000 was attained. In April, 1916, they were instructed to make 1,500 4·7-in. lachrymatory shells per week. During the steel shortage the factory employed slack time in machining 6-in. shell heads. With the spring of 1917 production of 4·5-in. shell mounted steadily, attaining a maximum of 9,000 in October. In January, 1918, the factory was turned over to the manufacture of aeroplane engine cylinders for the Rolls Royce Company, whose works for assembling engines were in the immediate neighbourhood, and manufacture of

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[1] D.A.O./Misc/1394; D.A.O./4/959; Hist. Rec./H/1121.24/9.

shell gradually decreased, finally stopping in September. The total output of the factory to the end of 1918 was 546,300 4·5-in., and 3,400 4·7-in. shells, 60,400 6-in. shell heads, 4,100 60-pdr. heads, and 28,500 aero engine cylinders.

In the beginning a large proportion of plant was second-hand, but this was gradually replaced and supplemented by new machines. In 1918 these were removed and a complete acetylene welding plant and oxygen generating plant substituted for the work then undertaken on Rolls-Royce engines.

From September, 1915, women were employed, and this factory was the first where they were employed on a large scale on heavy shell. Of the 1,109 workpeople employed at the end of 1917, 75·6 per cent. were women. In October, 1918, the percentage of women was 50·5, the total number employed being 537.

The average cost of 4·5-in. shell worked out at £1 5s. 6d., and the lowest figure reached was £1 1s. 1½d. In May, 1916, the Board was informed that its costs were the lowest attained.

The capital expenditure to 31 March, 1918, was £75,000.

The East Cumberland National Shell Factory (*Carlisle*).[1]

Difficulties of organisation, including an unsuccessful attempt to collaborate with the western side of the county, delayed the intention of the local Munitions Committee for East Cumberland to set up a factory, and it was not until 14 August, 1915, that the Ministry approved a Board of Management for the purpose.

Arrangements to take over empty engineering works in Carlisle having fallen through, the Board approached the War Office with a view to acquiring the Rifle Drill Hall, which was placed at their disposition on 18 September, free of rent for the duration of the war; the Territorial Force Association also lent their hall, which was used for stores until 1918, when it was required for its original purpose. A neighbouring dwelling house was also taken over, and a mission hall was adapted for a canteen.

The factory was administered by the Board, acting in close co-operation with the Munitions Committee and with the Area Engineer. In their agreement with the Ministry, signed on 9 October, 1915, the Board undertook an initial weekly output of 1,500 18-pdr. shells, rising as quickly as possible to 2,000. They quickly exceeded this estimate, and in 1917 were producing 4,000 shells. The total number delivered was 304,600 18-pdr. H.E. and 2,000 18-pdr. smoke. In addition they stripped, cleaned and re-made for the artillery large quantities of proof-shot.

In October, 1918, the employees numbered 257, of whom 81·3 per cent. were women.

The capital expenditure to 31 March, 1918, was £12,800.

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[1] HIST. REC./H/1121.22/2; D.A.O./Misc./1394; HIST. REC./R/1121/29.

Grimsby National Shell Factory.[1]

Before July, 1915, a group of Grimsby engineers concerned themselves in making plans for a National Shell Factory, and even went so far as to purchase lathes for the purpose on their own initiative. At the beginning of August their scheme was brought into line with others, a local Munitions Committee was formed, and finally, on 19 August, a Board of Management was authorised by the Ministry.

The factory in Victoria Street, Grimsby, which the Board was empowered to lease at a rental of £535 per annum, was an old two-storied building formerly used as a herring-curing factory. Extensive alterations were made, but in spite of these the buildings remained in many ways inconvenient and the lay-out congested.

The Board undertook to begin with an output of from 250 to 1,000 6-in. H.E. shells a week, working up to a larger number if required. On 4 December, 1915, the first 250 shells were delivered into bond, and output steadily rose to over 3,000 shells a week in 1917. A small quantity of 4·5-in. were produced at the end of 1918, the total number produced up to the end of 1918 being 318,300 6-in. and 16,500 4·5-in. H.E. The early costs were extremely creditable, working out in January, 1916, at 68s. 10d., and in December, 1916, at 56s. 5d. per shell. The prices paid to contractors at these dates were £4 10s. and £3 8s. respectively.

It was not definitely settled until June, 1916, to employ women in the factory. The heavy nature of the shell and the inconvenient lay-out militated against the free exercise of dilution, and it was not until June, 1917, that the Board were able to introduce the required 80 per cent. of female labour. In September, 1918, the total number employed was 534, and the percentage of women was 78·1.

The capital expenditure to 31 March, 1918, was £28,700.

Hartlepool National Shell Factory (Tyne and Wear).[2]

The establishment of a National Shell Factory was discussed by the Tyne and Wear Board of Management as early as September, 1915. At the beginning of November the Board laid a definite scheme before the Ministry, under which they proposed to lease certain new boiler shops belonging to the Central Marine Engine Works, West Hartlepool, at a rental of £3,500. The proposed factory was to be managed by the Central Marine Engine Works for a sum of £2,500 per annum, plus 1s. per shell completed in the factory. The estimate for management was considered too high, and was eventually reduced to £2,000, plus 1s., and it was also laid down that all proposals for capital expenditure must first be submitted to the Ministry. Additional clauses enabling the Board to run a factory were added in their original agreement with the Ministry on 22 December, 1915, and a legal agreement was drawn up between the Board and the company.

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[1] Hist. Rec./H/1121.21/3.

[2] Hist. Rec./H/1121.21/4; D.A.O./Misc./1394; (Printed) *Weekly Report passim.*

The factory was designed to produce 1,400 8-in. shells a week. In October, 1917, when an output of 1,500 was reached, it was proposed to turn over to 6-in. shell, when a request was made by the Admiralty that the factory should be handed over to them as a boiler shop. It was decided to comply, and in December, 1917, production was ordered to cease. The total output was then 81,100 shells. In November, 1917, 435 workpeople were employed, and in spite of the heavy nature of the shell, 81·6 per cent. were women, who were recruited locally.

The capital expenditure to 31 March, 1918, was £45,800.

Huddersfield National Shell Factory.[1]

On 14 May, 1915, a local Munitions Committee formed in the preceding month at Huddersfield made an offer to the War Office to use their spare machinery to manufacture shell, preferably 18-pdrs. They were given the choice of forming a co-operative group or running a National Shell Factory, and they chose the latter alternative. On 2 June a Board of Management was authorised to carry out this scheme.

A three-storeyed building, in Fitzwilliam Street, and stores at the corner of Viaduct Street and Green Street, were taken at a rental of £300. The Secretary of the Board of Management acted as general manager of the factory throughout.

Under the Board's agreement, the factory was to begin with an output of 2,000 18-pdr. shells a week. In spite of various delays production began in November, and by the middle of 1916 was between 4,000 and 5,000 a week. The factory then turned over to shell heads, reverting to 18-pdr. shell in the spring of 1917. In May, 1917, the output was 5,000, and ultimately rose to 7,500. About 470,100 shells in all were manufactured.

The original equipment of the factory was 100 machine tools, hired or purchased in the district. These proved unsatisfactory, and had practically all been replaced by the end of 1915.

Labour conditions were satisfactory. Women were employed from the beginning, and in December, 1915, numbered 250, as compared with 102 men. In October, 1918, women labour accounted for 83·6 per cent. of the total number (329).

The capital expenditure to 31 March, 1918, was £31,500.

The Irish National Factories.[2]

Dublin 18-Pounder Shell Factory.—On 22 June, 1915, a deputation of the Dublin Munitions Committee made a definite proposal to the Director of Area Organisation to establish a National Shell Factory for 18-pdr. shell at Dublin, which was accepted. Suitable plant was earmarked, but some delay occurred before premises were decided on. These were a margarine factory belonging to the Great Southern and

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[1] HIST. REC./H/1121.23/1 ; D.A.O./Misc./1394.

[2] D.A.O./Ireland/505, 123, 68, 111 ; D.A.O. Unregistered papers (Ireland) ; D.A.O./Misc./1394 ; Vol. II, Part II.

Western Railway Company; the situation was on the north bank of the Liffey about three miles from the Port of Dublin, and ample horse and motor haulage was available.

The adaptation of the building included the provision of shafting and fresh girder work.

The factory was at first under the immediate control of the Director of Munitions for Ireland, the factory manager, secretary and accountant being independent of each other and reporting separately to the Director. This did not prove very satisfactory and on the appointment of a new Board of Directors in September, 1917, a manager responsible only to them was appointed with full control over the entire factory.

Possession of the premises was not obtained until November, 1915, and production began in March, 1916. The output originally promised was 9,000 a week, but the total number of 18-pdr. H.E. and smoke-shell delivered into bond was 537,700, representing an average of about 4,000 shells weekly.

There was an amply supply of female and unskilled male labour in Dublin, though the girls, who were unaccustomed to the type of work, had to be trained. Skilled labour was scarce. In October, 1918, the total numbers employed in this, the 9·2-in. and the fuse factory, were 850, of whom 543 (63·9 per cent.) were women.

In June, 1918, a strike of the engineers employed in the factory took place and lasted three weeks. The workmen were warned that their action was an offence under the Munitions of War Act and thirty concerned were summoned before the munitions tribunal at Dublin and fined £3 each.[1]

Dublin 9·2-in. Shell Factory.—In March, 1916, the Ministry decided to establish a factory for 9·2-in. shell in Dublin on the same premises as the 18-pdr. factory, adequate accommodation being available. It was placed under the same management as the 18-pdr. factory.

The scheme was greatly delayed by failure to deliver plant and equipment and the first lot of shell was not bonded till April, 1917. An output of 500 shells a week was originally proposed, but the total deliveries were only 6,100 shell, and the proposed rate was never reached.

Dublin Fuse Factory.—The setting up of a fuse factory in Dublin had been for some time under consideration by the Ministry, before it was approved in May, 1916. This factory also was in the same grounds as the other Dublin factories, a new timber building with concrete foundations being built for the purpose.

The factory was at first regarded as part of the shell factory and was under the same management, but in September, 1917, was separated and henceforward had its own manager and system of accounts.

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[1] D.A.O./Misc./1394. Shortly afterwards four carpenters at Waterford Factory went on strike and under similar conditions were brought before the local tribunal and fined £10 each. It is understood that these two cases were the only instances in the United Kingdom in which the Ministry prosecuted members of trade unions for an illegal strike.

The output originally arranged for was 5,000 a week of fuse No. 101 in brass, and this was extended to 10,000 per week. The first delivery of these fuses was in March, 1917. The factory subsequently turned over to a new type, No. 103, of cast iron fuse with an output of 20,000 a week. A further change to No. 106 brass fuse was made later, with an output designed to reach 30,000. The total number of all types of fuses delivered was nearly 300,000.

This factory in addition undertook, in June, 1918, to manufacture aeroplane bolts and had delivered 193,160 at the time of the Armistice.

The capital expenditure on the three Dublin factories up to March, 1918, was £119,600.

Cork.—In 1915 the Cork Munitions Committee advocated the setting up of a national factory in the town, and in August were allotted plant for an 18-pdr. factory by the Ministry. This plant was subsequently diverted to Dublin and nothing further was done until the beginning of 1916, when Cork pressed its claims through the medium of the All Ireland Munitions Committee. The Ministry then approved a scheme for the manufacture of 4·5-in. shell and assigned the necessary plant.

The site chosen was a building, formerly used as a market, and known as St. Peter's Market, belonging to the Corporation of Cork, from whom it was rented. Railway facilities with Dublin were ample and there was a good shipping service from Cork to England.

The administration of this factory (as also of Waterford and Galway) followed the same lines as that of the Dublin Shell Factory.[1] Until 1917 the latter was considered the parent factory, and in certain cases workers were trained for the provincial factories, and tools supplied from the central tool room in Dublin. The employees at the Cork factory in October, 1918, numbered 147, of whom 112 (76·2 per cent.) were women.

There was considerable delay in equipping the factory, and the first delivery of 250 shell into bond did not take place till February, 1917. The total delivery of shell was 32,200.

The capital expenditure to March, 1918, was £14,000.

Waterford.—In the beginning of 1916, the All Ireland Munitions Committee clamoured for a National Shell Factory to be set up at Waterford, but it was not until the autumn that the Ministry decided to set up a factory for cartridge cases there.

A site, consisting of a disused railway siding, was taken over from the Great Southern and Western Railway, in November, 1916, under an Army Council Instruction, dated 19 November. An old engine shed was roofed in as a store and the Ministry constructed the main factory (a timber framed building with concrete floors), a powerhouse, cooling towers and the necessary offices. Both rail and water transport facilities were alongside the factory.

A plant designed to produce 20,000 cartridge cases per week was laid down. The first delivery into bond was made in August, 1917, and the total deliveries were 247,600.

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[1] *See* above p. 101.

In October, 1918, there were 529 employees, of whom 253 (47·8 per cent.) were women.

The capital expenditure to March, 1918, was £82,300.

Galway.—Towards the close of 1916, the Ministry consented to the establishment of a small 18-pdr. shell factory at Galway. A stone building, formerly used as marble and granite works, was adapted for the purpose and machinery sufficient to secure a weekly output of 500 shell was assigned. This machinery, which was second-hand, was received in January, 1917, when parts were found to be missing or badly damaged, leading to some delay.

There was practically no skilled labour available locally, and it was necessary to import mechanics to do the initial work and train such labour as could be obtained in Galway. The employees in the autumn of 1918 numbered 116, of whom 96 (82·7 per cent.) were women.

The total number of shells manufactured was 33,600.

The capital expenditure to March, 1918, was only £4,000.

Keighley National Shell Factories.[1]

No. 1 Dalton Lane.—On 31 May, 1915, the Army Council authorised the Keighley Board of Management to carry out a scheme for a National Shell Factory. Premises were rented for the purpose from Messrs. Prince, Smith & Sons, Keighley.

The Board of Management remained in very close touch with the administration of this factory, whose record was a particularly successful one.

The intended capacity was for 5,000 18-pdr., but by 1917 this output was more than doubled. In October, 1916, adjoining premises were taken, and plant for the production of 3·7-in. shell installed. The total output to the end of 1918 was 619,900 18-pdrs. (H.E. and Chemical), 152,200 3·7-in. and 21,200 6-pdr. anti-aircraft shell. The factory also turned out quantities of 6-in. shellheads.

The costs at this factory were very satisfactory, representing in 1917–18 a saving of £89,921 on the standard Ministry prices.

Female labour was freely used from the beginning, an average of 85 per cent. of women to 15 per cent. men being employed. The maximum numbers employed in the factory reached about 500 at the end of 1917. In October, 1918, of 417 workpeople, 83·7 per cent. were women.

The capital expenditure to 31 March, 1918, was £51,200.

No. 2 Dalton Lane.—In October, 1917, when the question of increasing the output of 6-in. shell was under ministerial discussion, the Keighley Board put forward a definite scheme for a factory which was formally authorised on 14 November, 1917.

A site, on which were the foundations of a foundry, was offered rent free by Messrs. Hall & Steels. On this the Ministry erected premises to be purchased by the firm at cost price less depreciation on the conclusion of the war.

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[1] D.A.O./3/743, 672, 641, 517 ; (Printed) *Weekly Report*, No. 160, VI (A.) (21.9.18).

An output of 3,000 or more shells was promised, but in January, 1918, when experimental work was in sight, the Ministry was compelled, by the shortage of steel, to order the abandonment of the scheme. A suggestion that the factory might manufacture aircraft parts was negatived, as the building proved unsuitable, and finally a scheme submitted by the Board in June, 1918, to produce either 4·5-in. or 18-pdr. castings was adopted in favour of the latter. In September, 1918, the factory was turning out 9,000 castings a week.

Leeds National Shell Factories.[1]

The conditions under which Leeds, the first of the National Shell Factories, came into being, have been indicated above.[2] Credit for the initiation of the scheme was largely due to the Leeds Forge Company, who furnished the first site and whose representatives were included on the Board of Management. Five national factories were eventually set up in Leeds to manufacture shell and components and were all administered locally by the Leeds Board of Management. With regard to their administration from head quarters, until the end of 1917 they belonged technically to the class of National Projectile Factories. They were, however, considered as Board of Management schemes and remained attached to the Department of Area Organisation until August, 1916, when they were transferred to the section dealing with National Projectile Factories. In 1917 one of the factories (Hunslet) turned over to the repair and manufacture of 18-pdr. guns, and in order to avoid dual control all the factories were transferred to the administration of the Gun Manufacture Department, and were known as the National Ordnance Factories, Leeds, from September, 1917. The local administration remained the same throughout the war, though in 1918 the Board of Management was known as the Board of Control.

Altogether, over 1½ million shell were produced by the Leeds factories, the output of the principal types to the end of 1918 being as follows: 4·5-in., 144,000; 6-in., 992,200; 8-in., 13,800; 9·2-in., 431,300; 12-in., 6,600; 15-in., 7,300. Large quantities of components were also produced and other work undertaken included the manufacture of 2-pdr. shell, 6-in. shrapnel shell, and mine sinker parts and the rectification of unfired shell and of shell recovered from the sea after proof at Shoeburyness.

The history of the individual factories was as follows:—

Armley Road.—This factory was the earliest to be established, the agreement between the Board of Management and the Ministry of Munitions being dated 20 May, 1915. New buildings intended for railway carriage shops were rented from the Leeds Forge Company, whose officials worked the factory under the general control of the Leeds Board of Management. Additional buildings were erected by the Ministry at a cost of £47,000.

[1] 94/Leeds/5; 93/Nat./139; C.S.M. 20564; Hist. Rec./R/1122.2/2, 1121.23/2, 11; (Printed) *Weekly Report, passim*; D.A.O./3/286, 358.
[2] *See* above, p.87.

The original offer of the Board was to manufacture 20,000 18-pdr. shell weekly, working up to 40,000, but they were almost immediately instructed to turn over to 4·5-in. shell and steps were also taken in July to equip a 6-in. shop. In spite of their willingness, local firms were only able to contribute about 40 lathes to the original equipment of 250, as their machines were not suited to the type of shell. The output of 4·5 in. was intended to be 5,000 a week, but this was considerably exceeded. Deliveries began in September, 1915, in November the promised rate was reached and by March, 1916, the weekly output was 10,000. Soon after this the plant was turned over to 6-in. on which the factory concentrated thenceforward. The original 6-in. shop was designed for 3,000, but in 1918 the total output averaged over 10,000 a week. The cost of the 6-in. shell was then £2 17s. 10d. and this represented a saving of £20,000 a month over the contract price of £3 6s. 10d.

A tool shop was established in connection with the factory. It supplied tools to all the Leeds factories and was extended in 1918 to include the manufacture of gauges.

After the factories were transferred to the Gun Manufacture Department the Armley Road Factory was known as National Ordnance Factory No. 3. A certain amount of rifling of guns was done here until the end of 1917, when the work was transferred to Hunslet. Gun inspection was also carried out, and in 1918 one of three additional bays taken over from the Leeds Forge Company was allocated to the Inspector of Guns for the before and after proof inspection of guns tested at the Meanwood Range, which was under the control of the Leeds Board of Management.

There was no early difficulty as to labour, and a contingent of 40 or 50 men was sent to Messrs. Armstrong's works at Newcastle to take three weeks instruction in shell and lathe work. In February, 1917, there were 1,471 men and 810 women employed in the factory and in October, 1918, the total number was 2,318, of whom 62 per cent. were women.

The capital expenditure on the factory to 31 March, 1918, amounted to £248,400.

Newlay.—Some time before 10 August, 1915, when Mr. Lloyd George interviewed the Leeds Board of Management, the Ministry had accepted their offer to erect a factory for the manufacture of 2,000 9·2-in. shell a week.

The site chosen was some seven miles from the Armley Factory, up the River Aire. The land was held under agreement with the Schoen Wheel Company, and all the buildings were erected by the Ministry, at a total cost of £78,000. The factory was controlled by the Leeds Forge Company.

First deliveries were promised by the close of March, 1916, but were delayed, the first shell being produced in April. At the beginning of 1917 an output of 2,750 shell per week was attained and during 1918 it averaged between 3 and 4,000. The factory was also equipped later for the production of 15-in. shell and in February, 1917, was turning out about 300 of this nature a week. The cost of producing 9·2-in. shell

at the beginning of 1917 was £8 15s. 11d., compared with the contract price of £10 17s. 6d. and of 15-in. shell £38 2s. 9d. as opposed to £40.

On the change of administration at the end of 1917, this factory became known as National Ordnance Factory No. 1.

At the beginning of 1917, the factory employed 1,307 men and 639 women. In October, 1918, the total number was 1,792 women, being 50·4 per cent. of the whole. The capital expenditure to 31 March, 1918, was £230,600.

Hunslet.—In 1916 the Leeds Board of Management established a further factory for the intended manufacture of 200 15-in. and 2,000 9·2-in. shell a week. Derelict premises at Goodman Street Works were taken over for the purpose under the Defence of the Realm Act, a rent of £582 per annum being paid for them.

The first 9·2-in. shell was produced at the end of August, 1916, and the first 15-in. a fortnight later, but the factory had hardly reached its maximum output early in 1917 when it was instructed to turn over to the relining and rifling of 18-pdr. guns.

Shell manufacture gradually ceased, though rectification of shell continued until the middle of 1918.

The first repaired gun was produced in August, 1917, and a few months later the manufacture of 18-pdr. guns Mark II began, the ultimate capacity being 150 repaired and 200 new guns a month. The factory, which was known as National Ordnance Factory, No. 2, undertook the 18-pdr. Mark IV gun in 1918, and other work done included the rifling of 60-pdr. guns and of 6-in., 8-in. and 9·2-in. howitzers and the manufacture of 18-pdr. recuperators and 6-in. and 8-in. recuperator liners. At the time of the Armistice a new carriage erection shop, to deal with 18-pdrs. Mark III, was in process of construction.

In February, 1917, before the change to gun work, the number of men employed in the factory was 1,563 and of women 960. The total numbers in October, 1918, were 1,750, of whom 397 (22·7 per cent.) were women. In March, 1918, output was delayed by a strike which began at Hunslet and spread to the other factories, involving practically all the workers and lasting for some days. The immediate cause was the dismissal of four men who had refused to carry out a foreman's orders, but there had been labour trouble for some time, particularly at Newlay, owing to a prospective alteration in bonus.

The total capital expenditure on the factory to March, 1918, including the cost of converting plant to gun work, was £274,400.

The Fuse Factory.—Early in 1916 the Leeds Board of Management took over a factory for the manufacture of the No. 106 fuse from the Leeds Munition Company and transferred the work to premises adjacent to the Armley Road Factory, which were part of the works of Messrs. Jonathan Hattersley & Sons, spindle manufacturers, and were rented from the firm. A gallery was added to the north side of the Leeds Forge Company's works, and this was at first used for assembling and gauging fuses and other components made by sub-contractors, but later this gallery was removed and the work was transferred to buildings rented for the purpose in Wellington Street and Sweet Street. In 1918 the

Armley Road Fuse Factory was known as National Ordnance Factory No. 4, Wellington Street as No. 5 and Sweet Street as No. 6. By the middle of 1918 the output of fuses from the three shops had reached 100,000 a week. The Armley Road Factory also made steel hammer castings, the output being about 40,000 a week and other components dealt with included primers, gaines, exploder containers, fuse hole plugs, etc., while primers and cartridge cases were also repaired.

In February, 1917, the labour employed on fuse work was 106 men and 774 women, while in October, 1918, of 1,470 employees 86·2 per cent. were women. The capital expenditure on the fuse department to 31 March, 1918, amounted to £26,400.

The Liverpool National Shell Factories.[1]

Haymarket.—In June, 1915, the Liverpool Committee decided to establish a national factory as part of their work. The Corporation offer, rent free, of part of a building used before the war as an agricultural produce market was accepted. The position was excellent, near the centre of the city and close to the docks and railway stations.

The management of the factory was under the control of the City Engineer, the Liverpool Board of Management maintaining a general supervision.

At the outset, the factory was organised to produce 18-pdr. shell. In June, 1916, it was instructed to turn over to machining 4·5-in. and 6-in. shell. The total number of shell manufactured by this and the other Liverpool factories was as follows:—1,873,900 18-pdr. (H.E. chemical and smoke), 46,100 2·75-in. H.E.; 6,600 60-pdr. H.E.; 797,300 4·5-in. H.E.; 431,900 6-in. H.E.; 26,600 8-in. H.E.

The original plant at the Haymarket factory, numbering about 60 machines, was lent by various Corporation Departments, Poor Law Institutions and other public bodies and by private firms. Additions were made from time to time, and when closed down there were about 350 lathes and other machines, and two acres, or half the total area of the market had been appropriated. The early plant was installed mainly with a view to quick delivery more than to economy of working but towards the end of its career the costs at this factory were becoming very satisfactory.

Labour was plentiful and the extent of female dilution was high, attaining to 83 per cent. of the total employed at the beginning of 1918. In October, 1918, of 1,603 employees, 79·6 per cent. were women.

The capital expenditure incurred was £131,000.

Cunard.—Towards the end of June, 1915, the Liverpool Committee entered into negotiations with the Cunard Steamship Company to establish a munitions factory. It was at first suggested that it should be run on non-profit-earning lines but the ordinary scheme of a National Shell Factory was almost immediately substituted.

The premises selected were a new warehouse for ships' fittings belonging to the company. The building was extended at the rear and

[1] Hist. Rec./H/1121.22/1; Hist. Rec./R/1121/29; D.A.O./Misc./1394.

an additional storey, with a concrete floor and steel girders, was added by the Ministry. The position, in a main thoroughfare and near the Gladstone Docks, was good.

The factory was under the direct supervision of the Cunard Company's Superintendent Engineer and was subject to the general control of the Liverpool Board of Management.

It was originally intended to manufacture 4·5-in. shell but Mr. (afterwards Sir Glynn) West, who visited the works in September, 1915, decided that part of the machinery should be turned over to 8-in. shell, and the manufacture of 6-in. was also taken up. The estimated output was 350 8-in., 2,000 6-in. and 2,500 4·5-in. shell a week.

Most of the machinery was of the type suitable to marine work and required to be specially adapted for shell. All tools and gauges were eventually made on the premises and also many of the spares so that the factory became practically self-contained.

Labour was plentiful throughout. The women, who in October, 1918, numbered 73·8 per cent. of the 1,110 employees, were of a superior class and speedily became proficient. They did their own gauging and in many instances their own tool-setting. All lathes were operated by women, and this factory had the distinction of producing the first 8-in. and 6-in. shell made by female labour.

The committee's proportion of the capital expenditure incurred was £16,600.

Edge Lane.—This factory was one of the early schemes of the Liverpool Munitions Committee. A steel frame structure, afterwards extended for stores, toolroom, etc., on the site of the Liverpool Exhibition of 1886 and subsequent years was chosen for premises, and was approved by Mr. West in September, 1915. The site was rented from the Liverpool Corporation at £900 per annum. The factory was designed to produce 4·5-in. and 6-in. shell forgings and also to manufacture cartridge cases. Owing to delays in the delivery of plant, the forging-factory did not produce until February, 1916, while there was even more serious delay on the cartridge case side, which did not receive its full equipment till August, 1916.

The factory was managed by a staff working under the general direction of the Liverpool Board. The inspection of forgings was carried out independently by the Liverpool Committee's technical superintendent.

The forging factory supplied the needs of the Liverpool Co-operative Group; the greatest number of forgings made in one week was 28,000. The total output was 1,055,300 4·5-in. forgings and 757,400 6-in. The authorised output of 4·5-in. short howitzer cartridge cases was 20,000 a week, the number actually attained was 28,000; during 1917 and 1918 a total of 704,300 was delivered.

All employees had to be trained, as the industry was new to the district; labour, both male and female, was abundant, except in the billet shops where the work was heavy and fit men scarce. The total number employed in October, 1918, was 757, 40·6 per cent. being women. The capital expenditure incurred was £96,000.

Lambeth Road.—In June 1915, the Liverpool Corporation offered to the Liverpool Munitions Committee part of the Lambeth Road Works of their Tramway Department to be used mainly as a depot for issuing material to and finishing the shell of their contractors. The offer was accepted and the factory was managed by the Manager of the Corporation Tramways acting under the general supervision of the Liverpool Board of Management. By the end of July 1916, it was in working order.

The main work of the factory was devoted to the finishing and rectifying of shell machined by the local contractors. In addition an output of 2,000 18-pdr. shells weekly was maintained. The capacity for finishing was originally estimated at 10,500 shells weekly but the actual numbers varied between 12,000 and 21,000. The total number of shell passed through the factory was 1,624,600 18-pdrs., 169,700 4·5-in., 40,600 2.75-in., 6,600 60-pdrs., 1,600 15-pdrs. and 17,100 18-pdr. smoke. In addition a large amount of material was distributed from the factory.

The lay-out was specially good. It was equipped originally with a large number of machines lent by the Corporation and private firms. These were subsequently reinforced by new tools purchased by the Ministry.

There was an abundance of female labour and a fair quantity of semi-skilled male labour available. Skilled labour was transferred from the Tramways Department as required. In October 1918, the total number employed was 363, of whom 86·5 per cent. were women.

The capital expenditure on this scheme was comparatively slight, being £22,000.

Bootle.—The difficulty of getting an adequate supply of satisfactory gauges led the Liverpool Board to consider the question of establishing a small gauge factory on national factory lines to cope with the demands of their district. On 2 November, 1915, ministerial approval was given to the scheme.

The premises of the Technical Engineering Company in Clyde Street, used for model and toy-making were taken over and additional accommodation provided by erecting a two storey building of wood and asbestos cement in the yard.

The plant consisted at first almost entirely of that taken over with the building, but was considerably augmented later. The factory turned out 20,000 gauges composed of over 1,500 distinct types and kinds.

There was not a large supply of skilled tool-makers, but women proved very adaptable to the work. Of the 52 employees in October 1918, 21 (40·4 per cent.) were women. The capital expenditure incurred was £6,300.

Chester.—In June 1915, the Corporation of Chester submitted a scheme for a National Shell Factory to the Liverpool Munitions Committee. The scheme was approved and submitted to the Ministry, receiving sanction in August 1915.

The boiler house of the electricity works of the city was placed at the disposal of the committee, rent free, by the Corporation. The administrative staff of the electricity works, acting under the general supervision of the Liverpool Board, managed the factory.

The original intention was to produce 15-pdrs., but in December, 1915, a change was ordered to 13-pdrs. and before this could be accomplished a further change to 2·75-in., which were manufactured till March 1917. A turn-over to 18-pdr. shell was then made. The estimated output was 1,000 a week, but owing to the frequent breakdown of plant, it was found difficult to keep up to 800 on two shifts; a day shift only was ultimately worked reducing output to 600 but with a corresponding reduction in working costs.

The equipment of the factory was very small, about 14 lathes and a few other machines, and was almost entirely second-hand, borrowed from various works and private owners. The factory only machined the shell, finishing operations being carried out at the Lambeth Road Factory.

An attempt was made to run the factory by local voluntary labour, but the results were not satisfactory. In September 1918, there were 37 employees, and of these 21 (56·7 per cent.) were women. The capital expenditure incurred was £2,400.

Manchester National Shell Factory.[1]

In October 1915, a scheme for a National Shell Factory was propounded by the Manchester Corporation Tramways Committee, who offered to set aside a portion of their Hyde Road Depot, rent free, for the purpose. After some delay spent in discussing preliminaries and settling the nature of the shell to be manufactured, the offer was accepted by the Ministry of Munitions early in 1916.

On 8 March, 1916, a Board of Management was authorised to administer the factory. It was entirely independent of the Manchester Board which already existed for a co-operative group, but included representatives of the latter among its members. A works manager was appointed to work under this Board.

The factory was equipped with machinery sufficient for an output of 2,000 4·5-in. shells weekly. It began with 500 a week and had attained the required number by 1917. Its total output by the end of 1918 was 88,900 shells.

The number of employees in October 1918 was 252, 79 per cent. being women. The capital expenditure to 31 March, 1918, was £16,500.

The Metropolitan Munitions Committee Factories.[2]

Ailsa Craig Works.—On 11 September, 1915, the Metropolitan Munitions Committee placed a contract with the Ailsa Craig Motor Company for 120,000 4·5-in. H.E. The contractors were to receive financial assistance towards building a new shop and installing the

[1] D.A.O./2/349; D.A.O./Misc./1394; HIST. REC./R/1121/29.
[2] HIST. REC./H/1121.27/1; (Printed) *Weekly Report, passim.*

necessary plant. At the beginning of 1916, the committee, while investigating the demands of the company for a further payment in advance, found preparations very behindhand, and on a far too elaborate scale. By the middle of April 1916, the new shop was still incomplete, while about 20,000 shells in various stages of machining were passing through the old shops. Acting in consultation with the Ministry the Metropolitan Munitions Committee decided in May 1916 to exercise their power under the Defence of the Realm Regulations to put in one of their officials to manage the works. Action was to be suspended for one month, when, if satisfactory progress were shown, it would be withheld. The company threatened to take legal action against the Metropolitan Munitions Committee, but conditions failing to improve, the Ministry persevered in its decision, and on 20 July, 1916, the Defence of the Realm Act was put into operation.

The works thus taken over were managed by the Metropolitan Munitions Committee, reporting to the Director of Area Organisation. Shell was henceforward produced at cost price, and the works classed as a National Shell Factory. On the dissolution of the Metropolitan Munitions Committee, in May, 1918, the factory came under the direct control of the Ministry, and in June, 1918, was placed under the administration of the Controller of Gun Ammunition, being classed as a National Projectile Factory.

The Ailsa Craig Works continued to manufacture 4·5 in. shell. In July, 1918, the output rose to over 2,000 shells a week, and in the following month varied between 3,000 and 4,000, attaining in September a maximum of 5,131. The total output to the end of 1918 was 253,200.

The numbers employed in March, 1918, were 608, of whom 54·9 per cent. were women. In February, 1919, the general manager brought forward an interesting suggestion as to the disposal of this factory, proposing to take it over and run it on a profit-sharing or co-operative basis. He was informed that a commercially sound scheme would be considered, and was allowed three months to complete his financial arrangement, and meanwhile given motor lorry repair work to keep the factory going. At the end of that time, however, negotiations were still pending, and it was decided to dispose of the factory in the ordinary way. The capital expenditure to 31 March, 1918, was £26,400.

College Park Works.—This small factory consisted of the works of Messrs. Klinger, alien enemies, manufacturers of engine packing, etc., and was taken over under the Defence of the Realm Regulations in October, 1915, by the Metropolitan Munitions Committee. Further tools were installed, and the shop was at first employed as accessory to the work of the Perivale Filling Factory, but later turned over to making shrapnel discs and sockets. It was classed as a National Shell Factory until the dissolution of the Metropolitan Munitions Committee, when it came directly under Ministry control, and was administered as a National Projectile Factory. There were only 122 employees in March, 1918, of whom 76 (62·3 per cent.) were women. The capital expenditure to 31 March, 1918, was £4,000.

The North Wales National Shell Factories.[1]

Wrexham.—In July, 1915, the Wrexham Munitions Committee presented a scheme for a National Shell Factory to the Liverpool Trustees, asking for affiliation with that body. The scheme was approved, and a grant made by the trustees to enable Wrexham to start work. Meanwhile, plans were being made to organise North Wales as a whole, and after some delay Wrexham was separated from Liverpool and attached to the North Wales Board of Management.

The site chosen for the factory was the Willow Road Depôt, a two-storied building, originally a malt house, lent rent free by the Wrexham Corporation. In 1917, a further building was rented from a firm of brewers in the town and adapted for varnishing rooms, examination rooms, canteen, &c.

By a formal agreement with the Ministry, signed 22 October, 1915, this factory was administered by the North Wales Board of Management. One works manager was appointed for the three factories administered by the Board.

The proposed output was 500 shells weekly, rising to 3,000 ; the actual output rose to 1,400 in 1916, 2,000 in 1917, and 4,500 in 1918. The production of 18-pdr. shell was interrupted for a short period in 1916 to take on 13-pdr. shell. In addition, all shell produced either by the Portmadoc and Carnarvon factories or the local contractors were finished at Wrexham. The total deliveries of shell into bond from the factory amounted to 54,600 13-pdr. H.E. and 840,400 18-pdr. H.E. and smoke.

The factory was equipped with about 50 machines, of which about two-thirds were the property of the Ministry, and the remainder hired from local manufacturers.

All the labour was drawn from the town or immediate surroundings ; women workers were plentiful, but male labour was scarce. With the exception of parting off, all operations on shell were carried out by women, who, in October, 1918, accounted for 86·1 per cent. of the numbers employed (259).

The capital expenditure to 31 March, 1918, was £9,000.

Portmadoc.—A census made in July, 1915, of machinery available in the North Wales area showed that there were 20 lathes and five drills at Portmadoc. On the strength of this report a sub-committee of the Munitions Committee recommended that one of the shell factories then under consideration should be established in that town.

The plan was eventually approved by the Director of Area Organisation, and the Boston Lodge Works, belonging to the Festiniog Railway were secured at a nominal rent. By an agreement signed on 22 October, 1915, the North Wales Board of Management undertook to manage the factory on behalf of the Ministry. The output of shell was to be 500 a week, rising to 3,900 a week, but the maximum was not attained. In addition to the hired machinery, four new lathes were added by the Ministry.

[1] D.A.O./Misc./1394 ; HIST. REC./H/1121.22/5 ; HIST. REC./R/1121/29.

Female labour was of a good class and plentiful, although many women had to come a considerable distance from their homes to the factory; mess accommodation was very successfully provided for these workers. Of the 61 employees in October, 1918, 49 (80·3 per cent.) were women.

The capital expenditure to 31 March, 1918, was £3,700.

Carnarvon.—Carnarvon was suggested by the North Wales Munitions Committee as the site for the third of the factories which they proposed to establish.

The Vulcan Foundry was taken over from Messrs. Humphrey Owen and Sons, manufacturers of machinery for slate quarries, etc., at a yearly rent of £180. On 22 October, 1915, the agreement, by which the North Wales Board of Management undertook to administer the factory, under the usual conditions, was signed.

The output promised was 500 shells weekly, rising to 3,000. This factory was not, however, well equipped; the hired lathes were old, and although they were reinforced by several new machines, output was considerably hindered.

Here, as in the other North Wales factories, female labour was both plentiful and freely used. In October, 1918, there were 80 workpeople, of whom 64 (80 per cent.) were women.

The capital expenditure to 31 March, 1918, was £2,800.

Nottingham National Shell Factory.[1]

The Nottingham Munitions Committee, formed in March, 1915, approached the War Office on 28 May with an offer to establish a National Shell Factory. Authority to proceed was granted to a Board of Management on 12 June, and the contract was finally signed on 12 July, a reconstitution of the Board having meanwhile taken place in order to make it more representative.

Part of a block of buildings known as Spring Close, formerly used for textile and lace manufacture, was taken for the factory at a rent of £200 and £80 for rates and taxes. Other portions of the same building were later taken over for general offices, stores, engine rooms, etc. The factory was administered by a factory manager acting under the general supervision of the Board.

The factory was originally equipped for an output of 2,000 to 4,000 13-pdr. In September, 1916, a change over to 3,000 2·75-in. a week was made, followed in December, 1916, by a further change to 4,000 18-pdr. shells a week. The total output to the end of 1918 was 346,800 13-pdr. H.E., 1,109,300 18-pdr. H.E. and smoke, and 54,000 2·75-in. H.E. In addition, the factory undertook the copper banding, base-plating and varnishing of the shell produced by the co-operative group, averaging about 12,000 18-pdr. weekly.

As the factory was one of the earliest to start, male labour was easily obtained. Later, when men became scarce, female labour was obtained in abundance owing to the depression in the local textile

[1] Hist. Rec./H/1121.24/7; D.A.O./Misc./1394.

trades, and of 538, the maximum number of workers (November, 1917), 84·9 per cent. were women. In September, 1918, there were 434 employees, of whom 81·3 per cent. were women.

The capital expenditure to 31 March, 1918, was £25,800.

Rawtenstall and Bacup.[1]

The Shell Factory (*Irwell Mill*).—On 29 September, 1915, the Rawtenstall and Bacup district, which had hitherto been administered by the Blackburn Board of Management, formed its own committee. A scheme for a National Shell Factory was submitted to the Ministry, who, on 11 December, 1915, authorised a Board of Management, drawn from the committee, to carry it out.

The Irwell Mill, Bacup, a one-storey building formerly used as a weaving shed, was offered, rent free, by Mr. Hargreaves, and with a few structural alterations involving no extensions, was adapted for a shell factory.

An output of 750 4·5-in. H.E. shells a week was originally offered. The maximum output eventually attained was over 2,000, and a total number of 156,900 shells was manufactured.

The plant consisted originally of 40 borrowed lathes not designed nor suitable for shell work. The first copper-banding press was converted from an old brick-making press, while a steam hammer was used for bottling throughout.

Skilled and semi-skilled labour was very scarce, but unskilled labour, consisting of mill operatives, quarrymen, and business people, was ample. Dilution was not at first considered suitable to the district, and was not introduced till the spring of 1917. In October, 1918, the numbers employed were 180, the percentage of women being 65·6.

The capital expenditure to 31 March, 1918, was £7,400.

The Rectification Factory (*Height Barn Mill*).[2]—At the end of 1917 the Board of Management put forward a proposal, which was approved, for the manufacture of 4,000 6-in. shells a week. Vacant premises were secured at Bacup, consisting of a weaving shed and four-storied mill, for which a rental of £50 a year was paid. While equipment was still in progress, in January, 1918, it was decided to abandon the shell manufacture scheme, owing to shortage of steel, and to use the factory instead for the rectification of forgings and shell.

Arrangements were accordingly made to alter the equipment to undertake the rectification of 6-in. shell forgings and 4·5-in. and 18-pdr. shells. Later, the finishing of the 6-in. forgings was also undertaken. Work on forgings began first, in the spring of 1918, and by the first week of June some 1,200 were ready for inspection. Deliveries of rectified 4·5-in. began at the end of June, but output of 18-pdr. was considerably delayed, and had hardly begun at the time of the Armistice. Owing to the varying nature of the defects to be rectified, it was difficult to promise a fixed weekly output, but in July the factory agreed to accept a weekly quantity of 5,000 4·5-in. and 5,000 18-pdrs.

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[1] D.A.O./Misc./1394 ; D.A.O./2/437. [2] D.A.O./2/1238, 1288, 1385.

The numbers employed in the factory were approximately 150, of whom 76 per cent. were women. At the beginning of 1918 an expenditure of £11,000 on the factory was sanctioned. The actual capital expenditure to 31 March, 1919, was £19,500.

Rochdale.[1]

In June, 1915, the Rochdale Committee, at that time affiliated to the Manchester Committee, made overtures towards establishing a national factory. The proposal was held up for some time by the difficulty of obtaining suitable premises, and was finally solved by the offer of the Rochdale Tramway Committee to place a portion of their Tramway Shed (then in process of erection) freely at the disposal of the Rochdale Committee. The offer was accepted, and on 25 October a Board of Management was authorised by the Ministry to organise the factory. The usual agreement was not signed until 17 November, 1915.

The Tramways Committee was represented on the Board, and one of their officials acted as Secretary of the factory. The administration was altered in July, 1916, and the factory was controlled until the close of 1916 by the Superintending Engineer and a member of the Board. In 1917 a committee, appointed by and answerable to the Board, was placed in control.

The factory was to be equipped for the production of 1,000 6-in. shells a week, and delivery was to commence in March, 1916. Owing to delays, mainly connected with the completion and adaptation of the building, the first consignment of shell was not produced until July, and the required maximum output was delayed until November. The total output to the end of 1918 was 90,200.

The question of dilution presented great difficulties in this factory. At the beginning of 1917 the total numbers employed were 366, of whom 62·6 per cent. were women. Recommendations were made to the Board (whose attitude was favourable) to raise the percentage of female labour, but the attempts to introduce women tool-setters led to threats of strike from the skilled workers, and the Labour Department of the Ministry decided in May, 1917, to suspend the question. In October, 1918, the Board was once more advised to proceed with dilution. At the end of the month the percentage of women was 70·9 on a total of 289.

The capital expenditure to 31 March, 1918, was £19,600.

Rotherham.[2]

A local Munitions Committee, composed of Rotherham and Barnsley engineers, was formed early in April, 1915, but owing to difficulties of organisation, resulting eventually in the separation of the two districts, it was not until 26 June, 1915, that the Board of Management was authorised to carry out a scheme for a National Shell Factory.

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[1] Hist. Rec./H/1121.22/7 ; Hist. Rec./R/1121/29.

[2] D.A.O./3/581, 688 ; Hist. Rec./H/1121.23/21 ; (Printed) *Weekly Report*, No. 164, VI, A, (19.10.18.)

The factory occupied two sites. First operations were carried out at the Brinsworth Ironworks, a portion of which was rented by the Ministry for £920 from Messrs John Baker, makers of locomotive wheels, etc. Finishing operations were performed at the Rother Ironworks, on premises rented for £756 17s. 6d., from Messrs. Owen and Dyson, railway wheel and axle manufacturers.

The factory was administered by the Board of Management, two of whose three members represented the lessors of the factory.

Under their agreement, the Board undertook to begin with an output of 500 4·5-in. H.E. shells a week, working up to 2,000. Deliveries began at the end of November, 1915, and reached 5,000 at the end of 1916. During 1917 manufacture was divided between 4,000 4·5-in. H.E. and 1,200 4.5-in. chemical shells a week. The factory reverted to 4·5-in. H.E. in 1918, but shortly before the Armistice arrangements were made to change over entirely to the 4·5-in. chemical shell. The total deliveries were 414,400 H.E. and 10,500 chemical shells.

The original equipment consisted mainly of machines collected from the district, and ill-adapted for shell manufacture.

Early difficulty was experienced with regard to skilled labour. By the beginning of 1916 women were employed on almost every operation throughout the factory, and in October, 1918, the percentage of female labour was 71, the total number of men and women employed being 636.

The capital expenditure to 31 March, 1918, was £53,000.

The Scottish National Shell Factories.[1]

Aberdeen.—The inauguration of the Aberdeen National Shell Factory was unusual. Early in 1917 the Aberdeen Board of Management was controlling a small co-operative group of three contractors, producing between them 1,600 6-in. shells weekly. Of these contractors Messrs. McKinnon undertook the finishing of the entire output. At this date their manager was convicted of certain malpractices in altering shell, and the Ministry decided that the firm must withdraw from the contract. Both the Ministry and the Board were very anxious not to interrupt output, and it was settled that the latter should take over Messrs. McKinnon's shops at 80 Spring Gardens, and run them as a National Shell Factory. The premises were accordingly taken over on 2 March, 1917, at a rental of £1,000 per annum.

The Board entered into a supplemental agreement with the Ministry, authorising them to work the factory as a National Shell Factory. They were to continue to receive their contract price (as a Co-operative Group), paying over to the Ministry the assigned value of that part of the work which was done by the factory. The scheme was a financial success, £22,000 profit being sent to the Ministry between June, 1917, and October, 1918.

Between the middle of 1917 and the Armistice the factory performed the finishing operations and painting of 99,700 6-in. H.E. shells.

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[1] HIST. REC./H/1122/54; D.A.O./Misc./1394; HIST. REC./H/1121.32/2.

The numbers employed in October, 1918, were 119, of whom 42 per cent. were women.

The capital expenditure involved to 31 March, 1918, was £600.

Dundee.—In May, 1915, Mr. West visited Dundee to advise the local Munitions Committee on the best disposition of available resources. On his recommendation it was decided by the committee to propose the establishment of a National Shell Factory. On 1 June their scheme received the formal consent of the War Office, and at the same time a Board of Management, elected by the committee, to administer the scheme, was approved.

Several sites had been suggested by the committee before Mr. West's approval was obtained. The building finally selected was a portion of the jute mills of Messrs. Grimond, of Dundee, by whom they were lent rent free to the Ministry. An adjoining tenement was purchased later and adapted for offices, cloakrooms, etc., making the factory self-contained with its own entrance and exit. A certain number of machines were obtained from the Dundee workshops, but the main equipment was provided from the steamship "Antilla," which had been captured with a cargo of machinery, and was lying in the Dundee Customs House at the time of Mr. West's visit.

The proposed output of the factory was a minimum of 5,000 18-pdr. H.E. shells weekly rising to 15,000. A start was made on production in September, and by November sufficient shells had been delivered into bond to enable proofs to be taken. In July, 1916, the Board was instructed to change over to 2·75-in. shrapnel, and owing to delay in receiving and installing the necessary plant the factory had to be temporarily shut down and its employees dispersed. When a start could be made, fresh workers had to be trained, with a consequent fall in output, 3,980 shrapnel only being delivered in the course of three months. Almost immediately a change back to 18-pdr. was made, and was accomplished without any stoppage of the day or night-shift. In February, 1918, the manufacture of 18-pdrs. was entirely superseded by that of chemical shell burster containers. The entire output of 18-pdr. shell during the two periods of manufacture was 561,100, of 2·75-in. shrapnel 4,300, of 6-in. chemical shell burster containers 579,000, and of 18-pdr. chemical shell burster containers 100,800. In addition, a considerable number of forgings for these different types of shells was made in the factory.

Both output and cost of production in the factory were excellent, and the success must be considered to be largely due to the early advantage of Mr. West's technical advice both in the choice of a site and its subsequent lay-out.

No difficulty was experienced in obtaining a suitable and good class of female and unskilled labour. Skilled labour was always difficult to secure. In June, 1915, thirty turners were sent to train at Elswick. At the end of 1917, 351 workers were employed, 74·3 per cent. being women. In October, 1918, of 427 employees, 325 (76·1 per cent.) were women. The capital expenditure to 31 March, 1918, was £34,000.

The South Wales National Shell Factories.

Uskside[1]—The Uskside works occupy an excellent position on the west bank of the Usk, with sidings connected at two entrances with the Great Western Railway and branch lines to each department. Their immediate pre-war employment was the manufacture of steam and electric mining plant for the Uskside Engineering Company, but already in May, 1915, they had turned over to the production of munitions in the shape of proof shot and 18-pdr. shell. They were suggested at that date by the Welsh National Committee as furnishing a suitable site for a national factory and after some negotiations the Ministry decided to take over the whole buildings as a going concern for the duration of the war. The transfer was formally accomplished on 1 July, 1915. The rent paid was £460 per calendar month. The works were administered by a Board of Management appointed by the Ministry and composed of the former Board of Directors.

The manufacture of 18-pdr. shell which had already begun was continued till the summer of 1917, when production was stopped. A new erecting shop for 6-in. shell had been built before the Ministry took over and in March, 1916, deliveries began and were sent out in regularly increasing numbers till 1918, when the plant was turned over to 4·5-in. shell. The total output from the factory was 24,500 18-pdr; 119,700 6-in. and 16,100 4·5-in.

The Uskside works were by no means limited to the production of shell and during the Ministry's tenancy they produced proof shot of various calibres and also proof shot forgings, some of these being made from recovered proof shot, other work included gun carriage forgings, pedestals for naval guns, breech pieces for 9·45-in. trench howitzers, and rudders and other gear for standard ships. Moreover, they maintained their pre-war work in carrying out urgent repairs for colliery plants.

The question of dilution, which was introduced into the factory in October, 1915, presented no special difficulty and the women, like the men, kept a shift of about 60 working hours. A canteen, opened in August, 1915, by the Y.M.C.A. assisted by voluntary workers, provided food and recreation for the employees; from February, 1917, it was administered by the Board of Management. In October, 1918, there were 471 workpeople, of whom 46 per cent. were women.

As little alteration as possible was made to the existing works. The new 6-in. shell shop, however, the cost of which was borne by the Ministry, was fitted with the latest appliances for reducing handling to a minimum, including bench conveyers which, by keeping the shell at the same level as the lathes from start to finish, made it possible to operate nearly the whole shop with female labour. The capital expenditure involved by the adaptation of and additions to the works was £61,900.

Ebbw Vale.[2]—In June, 1915, the Welsh National Committee negotiated a scheme by which one of the shops of the Ebbw Vale Steel

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[1] D.A.O./5/505, 510; D.A.O./Misc./1394, 238.
[2] D.A.O./Misc./238; D.A.O./5/505; HIST. REC./R/1121.25/7.

Iron and Coal Company engaged on manufacturing 1,000 18-pdr. shells for Woolwich, should be made a national factory, these shell to form its first delivery.

The premises were offered rent free by the company. The factory was administered by a Board of Management, the Chairman of which was Managing Director of the company.

The promised output was to be 1,000 18-pdr. shell weekly, rising as soon as possible to 5,000. On 11 August, 363 shells had been delivered. Shortly after, Mr. West authorised an extension for the production of 5,000 60-pdr. shell weekly.

By the close of 1915, the effects of certain disadvantages inherent in the scheme began to appear. The factory was 19 miles from Newport and the infrequent train service, together with the heavy congested goods traffic, led to labour and other difficulties which were reflected in very heavy costs of production. In November the cost price of the 18-pdr. shell was 17s. 7d., and in December, 20s. 2d. The Director of Area Organisation under the circumstances strongly advised the abandonment of the 60-pdr. scheme. In spite of the advantages of their early start, the factory had only attained a weekly total of 1,000 shells at this date, and though output slightly increased at the beginning of 1916, costs continued very high. In May, any idea of extension was definitely rejected and the Board warned that drastic measures would be taken unless better results were obtained. In July, 1916, the D.A.O. Executive Committee finally decided to close down the factory. The total deliveries amounted to 89,200 shells.

The capital expenditure to 31 March 1918, was £32,200.

Newport (*Maesglas*)[1]—In the autumn of 1915, the Ministry decided to establish a second factory at Newport for 60-pdr. H.E. shell. The fitting shops recently completed at the Great Western Railway engine sheds at Maesglas, some two miles out of Newport, were acquired for the purpose. An auxiliary shop for producing the shell noses was also taken over from the Tyne Engineering Works, ship repairers in the same town.

The factory was administered by a Board of Management composed of the same persons as the Ebbw Vale Board but with a different chairman and secretary, and the meetings were held independently. Responsible to the Board were a chief accountant, who also acted as a commercial superintendent, and a factory manager.

Maesglas suffered more than usual from delay in obtaining machinery, and it was not until late in March, 1916, that appreciable progress was made with the erection of plant. Shell began to be delivered into bond in June, 1916, and by November the factory was producing a weekly average of 7,000 shells. The total quantity delivered into bond was 601,200. In addition, 229,700 nose bushes for 4·5-in. and 9·2-in. shell were made in the factory.

The supply of labour presented, at the outset, considerable difficulties, but female labour was abundant, once the question of training

[1] D.A.O./Misc./1394 ; D.A.O./5/143, 505.

had been surmounted. In March, 1918, when the work was re-organised both to introduce a new Mark of shell and reduce output, considerable trouble was threatened by the necessary change to two eleven-hour shifts for both male and female workers. All male employees, numbering about 1,200, were discharged and were re-engaged as required on the new terms. This resulted eventually in improved earning capacity for the workers, who were paid a day rate plus a production bonus, and the trouble disappeared. In October, 1918, the employees numbered 974, 74·3 per cent. being women.

Owing to the distance from Newport, transport facilities had to be provided for the workers and a service of motor trains, run by the Great Western Railway, was instituted at the cost of the Government. Little adaptation was required for the Maesglas works, but considerable alterations, at Government expense, were made to the shop at the Tyne Engineering Works. Canteens, cloak-rooms and other offices were erected in both works. The capital outlay by the Ministry to 31 March, 1918, was £112,400.

Cardiff.[1]—On 30 June, 1915, the Cardiff Board of Management received ministerial approval for the establishment of a national factory. The site chosen was a brick building hitherto used for spinning hemp and making yarn and rope. Temporary buildings for inspection, bond and store rooms were subsequently added on adjoining sites belonging to the Taff Railway Company, who allowed free occupancy. The factory was situated at the south end of Cardiff within easy distance of tramways, but until a siding was laid into the factory yard, early in 1916, the railway facilities were poor.

The factory was designed for a weekly output of 1,000 rising to 5,000 18-pdr. shells and by the summer of 1916 had produced 37,445 shell. Manufacture then ceased and extensive alterations and adaptations of machinery were made to produce 60-pdr. shellheads, of which 68,913 were machined by the end of 1916, together with a number of 6-in. proof shot. To meet the renewed demand for 18-pdr. shell the factory was again re-laid out on the basis of an output of 5,000 per week. The weekly output eventually reached 7,000, and the total deliveries to the end of 1918 were 497,900.

Skilled labour was fairly plentiful, unskilled labour, both male and female was abundant. The whole of the production and a large proportion of tool setting and gauging was done by female labour, which in October, 1918, represented 78·3 per cent. of the total number employed (470).

The capital expenditure entailed in the setting up of this factory was £28,500.

Swansea.[2]—On 23 June, 1915, a deputation representing the Swansea district of the Welsh National Committee visited the Ministry,

[1] D.A.O./Misc./1394 ; D.A.O./5/503 ; HIST. REC./R/1121.25/6.

[2] D.A.O. / 5 / 504, 534, 523, 600, 197 ; HIST. REC. / R / 1121 . 25 / 8 ; HIST. REC./R/1121/20.

when it was decided to accept their offer to establish a National Shell Factory in the town. Suitable premises at Landore, Swansea, were offered by Messrs. Baldwin, rent free; additional cloak rooms, tool rooms, etc., were partly paid for by the Government.

The factory was administered by a Board of Management authorised by the Ministry on 26 June, 1915. The Managing Director of Messrs. Baldwin was chairman.

The factory was originally intended for 18-pdr. H.E. shell but before the close of 1915, it was decided to produce 4·5-in. as well. In the middle of 1917 the capacity was 4,000 4·5-in. shells and 2,500 18-pdr. a week. In April, 1918, the manufacture of 18-pdr. H.E. was stopped and the factory turned over instead to 18-pdr. steel chemical shell. The total output of 18-pdr. H.E. was 215,100 and of 4·5-in. 419,900.

The factory suffered at the start from an incompetent works manager, and in October, 1915, the plant had to be reconstructed. The results appeared in very high initial costs of manufacture, but in October, 1917, the costs both for 4·5-in. and 18-pdr. H.E. were stated to be the lowest on record for any National Shell Factory.

The total number of workers in October, 1918, was 636, the percentage of female labour being high (87·6). The capital expenditure was £40,500.

Llanelly National Shell Factory.[1]—In September, 1915, Llanelly engineers, who had hitherto been grouped under the Swansea Board of Management, applied for permission to establish a National Shell Factory for 6-in. shell. The request was favourably regarded by the Ministry, and with the approval of the Welsh National Committee for Munitions of War, a Board of Management was nominated which was authorised by the Ministry of Munitions on 27 September, 1915.

The firm of Messrs. Richard Thomas, tinplate manufacturers, the prime leader in the movement, offered to the Board, rent free for the duration of the war, excellent premises known as Burry Extension Works with the use of such plant installed there as might be required for the factory. The site was taken over by the Board as from 19 September, 1915.

The agreement between the Ministry and the Board was signed on 23 October, 1915. The preliminary output was to be 1,000 6-in. shells a week, the first delivery was to be on 1 February, 1916, and was actually made on 26 February. A capacity of 4,500 shells a week was attained by 1917, but in December of that year the factory under their current authorisation, promised a delivery of 2,250 only. By the end of 1918 a total of 381,400 shells had been manufactured.

The capital expenditure to 31 March, 1918, on this and the Rectification Factory was £171,500.

[1] D.A.O./5/520, 610, 566, 22, 22a; Hist. Rec./R/1121/29; (Printed) *Weekly Report, passim.*

Llanelly Rectification Factory.—In September, 1916, it was decided to build a rectification shop to be run by the Board of Management of the Llanelly National Shell Factory.

By a supplementary agreement with the firm of Messrs. Richard Thomas, dated 20 September, 1916, the Board acquired rent free a site adjacent to the Burry Extension Works. A new building was erected here at the Government expense.

It was intended to rectify all shell up to 6 in. and capacity for about 40,000 rectifications a week was provided. This number was never attained, the average for the last half of 1918 being 16,000 6-in. and 18-pdr. shells a week, of which the latter shell comprised the larger number. The total deliveries were 505,900 18-pdr. and 284,000 6-in.

The labour employed at the Shell and the Rectification Factory totalled 1,440 in October, 1918, the percentage of female labour being 73·7.

The West Cumberland National Shell Factory (Workington).[1]—Apart from the delay incidental to the difficulty of organising the county the West Cumberland Munitions Committee at first devoted its energies to establishing a co-operative group and it was not till the close of September that they finally approached the Ministry with a scheme for a National Shell Factory. Acting on the report of the Area Engineer the Ministry gave official sanction on 25 November, 1915.

The site chosen for the factory was the Hawkshead Foundry, Workington, belonging to Messrs. T. A., J., and P. Milburn, which had been standing empty for some years and the factory was lent to the Ministry free of charge, £40 yearly ground rent being payable by the Ministry.

The West Cumberland Board by whom the factory was administered originally offered to produce 2,500 18-pdr. weekly rising to 3,000. Deliveries did not begin till August, 1916, but rose to 4,000 weekly in 1917, eventually attaining a maximum of 4,500. This included a small weekly sub-contract delivery of 500 rough bored and turned shells. The total number of 18-pdr. shells (H.E. and smoke) delivered to bond was 359,400, and a number of 6-in. and 18-pdr. base plates were also machined for other factories. At the date of the Armistice the factory had just turned over to 18-pdr. chemical shell.

This factory was selected by the Ministry in February, 1918, for an experiment in a one break day shift and a 50 hour week. The hours agreed to be worked were from 8 a.m. to 6 p.m. and a start at 7 a.m. on Saturdays. After three months trial the majority of workers were in favour of the experiment in spite of an evident desire for an earlier stopping time; at the end of the second three months there was no doubt about the popularity of the new hours.

The numbers employed in October, 1918, were 181, 84 per cent. being women. The capital expenditure to 31 March, 1918, was £12,700.

[1] HIST. REC./H/1121.22/2, 3; D.A.O./Misc./1394; HIST. REC./R/1121/29; Vol. II, Part II.

CHAPTER IV.

NATIONAL PROJECTILE FACTORIES.

I. Introduction.[1]

(a) *Initiation of the Factories.*

In July, 1915, deliveries of heavy shell fell far short of promises, and at the same time the necessity of meeting the new gun programme involved a large expansion of output. The weekly programme of shell manufacture aimed at was 39,000 60-pdr. shrapnel; 24,000 60-pdr. H.E.; 41,000 6-in. H.E. and 32,000 9·2-in. H.E., a total of 136,000. At a conference held on 13 July with representatives of 9 armament firms to consider by what means this programme could be attained, it was stated that there was no immediate prospect of increasing output of shell over 4·5-in. to more than 32,000 a week. Discussion at once revealed the impossibility of improving the position by extending existing works, but the firms were strongly opposed to the alternative suggestion for the establishment of national factories independent of them. A solution was found in an arrangement by which the armament firms agreed to build and manage new factories, in connection with their existing works, the cost of building and all manufacturing expenses being paid by the Government. The factories erected under these conditions were known as National Projectile Factories.

Detailed arrangements were under discussion throughout the rest of July. The main provisions of the scheme which was finally evolved may be summarised as follows :—

The factories were to be erected and equipped at government expense, and were to remain the property of the Government. The Government was also to provide raw materials, give any possible assistance in the provision of labour, and be responsible for all working expenses, including wages, with the exception of the salary of the manager. The latter was to be appointed by, and responsible to the managing firm, but the appointment was to be approved by the Minister, who would have the right at any time of recommending the dismissal of the manager or any member of the staff.

As a fee for supervising erection and equipment each firm was to receive a percentage of the expenditure involved, this percentage being fixed at 4 per cent. on the first £250,000, 3 per cent. on the second £250,000, 2 per cent. on the third £250,000, and 1 per cent. on anything over £750,000. On the production stage being reached, each firm was

[1] Hist. Rec./H/1300/2, 3, 13, 15. For the place taken by these factories in the general organisation for shell manufacture, *see* also Vol. X, Part III.

to receive as remuneration for management and supervision, a fixed sum per shell—5s. for each 9·2-in.; 1s. 6d. for each 6-in.; and 1s. 3d. for each 60-pdr. shell approved—or such sum as might, by agreement, be substituted in order to give direct encouragement to increase of output or economy in production.

This scheme was followed in the agreements under which factories were erected at Cathcart by Messrs. G. & J. Weir; at Dudley by Messrs. Harper Sons & Bean; at Glasgow (Cardonald, Moss End & Mile End) by Messrs. Beardmore; at Hackney Marshes by Messrs. Dick Kerr & Company; at Lancaster by Messrs. Vickers; at Renfrew by Messrs. Babcock & Wilcox; and at Sheffield (two) by Messrs. Hadfield and Messrs. Firth. The only National Projectile Factories which differed, save in detail, from the type were those at Nottingham, where Messrs. Cammel Laird refused to accept any fee for erection or management; and at Birtley where a factory was built by Messrs. Armstrong Whitworth, the agreement with whom was later converted into one with the Belgian Government, who worked the factory with Belgian labour.

Mention must also be made of certain factories which were not erected as National Projectile Factories, but were classed with the group for purposes of headquarters administration. A factory at Darlington, built by Messrs. Armstrong Whitworth at Government expense and managed by the North-Eastern Railway Company as sub-contractors to Messrs. Armstrong, was taken over by the Ministry in the summer of 1916.[1] A factory at Ponders End, where a large output of heavy shell was produced by the Rees Roturbo Manufacturing Company, of Nottingham, from the end of 1914, was taken over in 1918. The factory's output was satisfactory, but misunderstanding had arisen between the company and the manager of the works, and the latter in some cases negotiated direct with the Ministry for contracts, and carried them out although they were repudiated by the company. To put an end to this unsatisfactory state of affairs, it was decided, since the output was needed, that the Ministry should take over the factory. It did not actually come under the control of the Gun Ammunition Department until the beginning of November, 1918, but the arrangement was retrospective as from 31 March, 1917. Though classed as a National Projectile Factory, it was occasionally called a National Ordnance Factory, owing to the fact that in 1918 the most important, though not the largest, part of its output consisted of 6-pdr. guns for tanks and some gun repair was also done. The total shell output from 31 March, 1917, to the end of 1918, was 294,600 6-in. H.E., 299,700 8-in. H.E., and 700 12-in. By 31 March, 1919, a sum of £812,200 had been expended on this factory. Two other factories in the London district, the Ailsa Craig and College Park Works, administered by the Metropolitan Munitions Committee until 1918, were taken over on 1 June of that year, as a result of the decision to transfer the administrative work of the Metropolitan Munitions Committee to the Ministry. At Leeds, a group of factories engaged on shell manufacture were classed as

[1] *See* below, p. 134.

National Projectile Factories for two years, though they were administered as National Shell Factories by the Leeds Board of Management. In 1917, one or two of the Leeds factories undertook gun manufacture and repair, and from the end of that year all of them were known as National Ordnance Factories. The history of the Leeds factories, and of Ailsa Craig and College Park, has been related in the chapter dealing with National Shell Factories.[1]

In close conjunction with the National Projectile Factories was the National Components Factory at Tipton, which was established early in 1917 as a central source of components for these factories. It was originally erected by the Ministry on land lent for the purpose by Messrs. Bean, who undertook to operate it under an agency agreement. The plant for manufacture of shrapnel components, H.E. shell heads and nose bushes was transferred from the National Projectile Factories and the works were subsequently turned over to the manufacture of fuses.[2]

(b) *Construction.*

Preliminary estimates of the cost of buildings and plant for eight factories drawn up in September, 1915, amounted to over £5,000,000, and it was recognised that this figure would probably be exceeded. Later, with the addition of three more factories, the capital cost was estimated at about £7,000,000. In view of this heavy expenditure, it was decided in October, 1915, that the land on which the factories were erected should either be purchased outright or taken on a long lease. As the Minister of Munitions had no legal power to hold land in his official capacity, land was conveyed to the Secretary of State for War in cases where it was intended to be used permanently for military purposes, or to the Office of Works, possession and control being then given to the Minister by a formal departmental minute. In every case except one, definite agreements were reached as to sites, and the Ministry became either owner, lessee for 21 years, or tenant for the duration of the war. At Cathcart, however, the owner of the site had given an undertaking to the feuars of the neighbouring property that no industrial buildings should be erected on the ground, and the land had, therefore, to be taken under the Defence of the Realm Act.

In the case of all the Projectile Factories save one (Mile End, Glasgow) new buildings were erected. Construction contracts were arranged by the armament firms concerned, who were responsible for designing the buildings, but drawings and estimates were submitted to the Ministry for approval. The work of erection was supervised by the Office of Works until October, 1915, when the Director of Factory Construction assumed the responsibility. Construction began in the autumn of 1915, and the factories came into operation at various dates in the course of 1916, the first to begin production being Messrs. Firth's factory at Sheffield, and the last, Moss End.

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[1] *See* above, p.105 and p.111.

[2] C.S.M. 29758.

(c) *Administration.*

In May, 1916, a National Projectile Factories Executive Committee was set up in the Ministry to deal with questions of vital importance or special difficulty arising in connection with the factories. The matters which came before the committee included changes of design, alterations to contracts, requests for additional capital expenditure, the supply of labour and of small tools. In January, 1917, the committee was merged in the Shell and Components Manufacture Executive Committee, which dealt with all questions relating to shell production until the end of the year, when it was dissolved on the formation of the Munitions Council. Executive action with regard to the Projectile Factories was taken by a section of the Shell Manufacture Department.

A resident engineer was stationed at each factory to watch the technical side of production. Elaborate and detailed returns were required from the factories. The statements submitted each week included details of the number of machines available for, and the time taken in, each operation; the number of shell rejected, distinguishing between rectifiable shell and scrap, the total output of forgings and the average output per press and per worker. In addition to the weekly returns, an efficiency chart was filled in monthly giving details of the labour employed, the number of machine hours worked, the total output of shell, etc. From these data a comparative table was drawn up showing the work of all the factories, classified according to the nature of shell made. This efficiency system is interesting, apart from its practical results, as an example of the application of the principles of scientific management on a scale hitherto unknown in England.

Occasionally, when the management of a factory proved unsatisfactory, the Ministry exercised its right of requiring a change in the supervisory staff. Reorganisation was carried out at Cardonald in August, 1916, and at Dudley a year later, and a new general manager was appointed at Lancaster in January, 1917. At Hackney Marshes, prolonged attempts to secure improved organisation were unavailing, and the Ministry took over the direct control of the factory in August, 1917.

The Ministry also exercised supervision with regard to the equipment of the factories. The firms were at first allowed to order machine tools from what sources they chose, though Ministry approval of all orders was required; but later a considerable amount of allocation was necessary, and each firm was obliged to take some American machinery. Control over machine tools became increasingly stringent, and from August, 1916, orders for spare parts as well as for new tools had to be submitted for approval. Considering the Projectile Factories as a single productive group, the Ministry also exercised the right of balancing plant. Factories were periodically inspected and idle machinery recommended for transfer elsewhere. The best possible use of the small tools available was secured by representatives of the Small Tools Section stationed at each factory.

Throughout 1916, the Projectile Factories had priority over National Shell Factories and contractors for the supply of both machinery and raw materials. Shortage of the latter, however, hampered most of the factories, particularly at the end of 1916 and beginning of 1917. At Dudley, for example, the 6-in. forges were idle for this reason during the first week of January, 1917, and a number of machines were idle the following week at Hackney Marshes.

(d) *Work done by the Factories.*

The natures of shell which it was originally intended should be manufactured in National Projectile Factories were 60-pdr. H.E. and shrapnel, 6-in. H.E. and 9·2-in. H.E. Subsequently, 8-in. was substituted in some cases for 9·2-in., while 12-in. was undertaken in Messrs. Babcock and Wilcox's factory at Renfrew. The factories confined themselves to medium and heavy shell until early in 1917, when a reduction of the shell programme placed some of their machinery in excess of requirements. In order to utilize this surplus capacity without distributing the machinery, work of various types was undertaken during 1917. Guns were repaired at Lancaster, Cardonald, Sheffield (Hadfield's), Nottingham, and Leeds, and gun parts were made at Dudley. 18-pdr. shell was produced at Cardonald, Mile End, Dudley, and Darlington; 4·5-in. H.E. at Sheffield (Firth's); grenade mortars at Lancaster; and a certain quantity of Italian shell (149 mm.) at Nottingham. Some aero-engine work was done at Dudley. In 1918, 6-in. chemical shell was produced by Cardonald, Mile End, Hackney Marshes and Dudley, the last having started this type of shell during the previous year, and 4·5-in. chemical shell was produced by Sheffield (Firth's).

In a few cases the entire capacity of a factory was, on the reduction of the shell programme, diverted to new work. Cathcart gave up shell manufacture in May 1917, and turned over to aeroplane work. Nottingham, starting gun repair early in 1917, later turned to gun manufacture; shell production gradually ceased and the factory was classed as a National Ordnance Factory from 1 October, 1917, though some shell were produced until the middle of the following year. Messrs. Hadfield's factory at Sheffield also made guns in addition to repairing them, and became a National Ordnance Factory in 1918.

The total output of the principal types of shell produced by the factories during the war is shown in the following table, the figures in which include the whole shell output[1] of the Leeds factories, classed as National Projectile Factories for headquarters purposes; the output of Darlington from the date of nationalisation (1 July 1916); that of Ponders End from 31 March, 1917; and that of Ailsa Craig from 1 June,

[1] The output was 144,000 4·5-in.; 992,200 6-in.; 13,800 8-in.; 431,300 9·2-in.; 6,600 12-in.; and 7,300 15-in.

1918. Details of the output of individual factories will be found in Appendix II.

Nature of Shell.	1915.	1916.	1917.	1918.	Total.
18-pdr. H.E.	—	—	464,700	83,200	547,900
S.	—	—	454,400	609,400	1,063,800
4-in. H.E.	—	—	—	16,200	16,200
4·5-in. H.E. and Chemical.	37,300	105,200	583,800	651,700	1,378,000
60-pdr. H.E. and Chemical.	—	491,800	815,600	1,215,000	2,522,400
S.	—	527,500	1,159,300	1,450,600	3,137,400
6-in. How. H.E. and Chemical.	—	864,800	2,921,700	4,138,300	7,924,800
8-in. How. H.E. ..	—	234,100	957,500	871,100	2,062,700
9·2-in. How. H.E. ..	—	328,100	736,600	378,200	1,442,900
12-in. How. H.E. ..	—	4,900	2,000	6,500	13,400
15-in. How. H.E. ..	—	1,400	4,600	1,300	7,300
Grand Total ..	37,300	2,557,800	8,100,200	9,421,500	20,116,800

The table illustrates the rapid increase of state manufacture during the years 1916 and 1917. From a small quantity of one type of shell produced by one factory (Armley Road, Leeds) in the second half of 1915, the output of the National Projectile Factories rose to over 2½ millions in 1916, half of this being produced in the last three months of the year. The 1916 output was more than trebled in 1917, and in this year the maximum output of some of the heavier types (8-in., 9·2-in. and 15-in.) was attained, the 1918 figures showing a comparatively small increase on the aggregate.

(e) *Labour.*

Shortage of skilled labour was a difficulty which beset all the factories, although their requirements had priority. In the summer of 1916, a small proportion of skilled tool-room staff was transferred from factories turning out lighter shell, and also from the machine tool trade, but this did not entirely obviate the difficulty. As regards unskilled labour, some of the factories, such as Lancaster, Nottingham and Messrs. Firth's at Sheffield, employed women from the start, Messrs. Firth's factory, in particular, producing excellent results. Other factories were strongly opposed to the extension of dilution, notably Hackney Marshes, a factory which throughout suffered from labour troubles. Difficulty was also experienced in getting some of the factories to accept war munition volunteers.

In March, 1917, female labour represented 39·6 per cent. of the total employees (about 55,000); but at the time of the Armistice the proportion was higher, the percentage of women in October 1918 being 50 per cent.[1] on a total of 39,500. In addition, the total number of employees in the Tipton Fuse Factory in October 1918 was 3,104 and 65·6 per cent. of these were women.

(*f*) *Expenditure and Costs.*

The result of the first year's working of the National Projectile Factories was shown when their accounts up to 31 March 1917, were investigated. The average cost of shell produced compared very favourably with the average contract price for the same period. For instance, 60-pdr. H.E., cost 43s. 8d. compared with the contract price of 51s. 3d.; 8-in. H.E. 100s. 7d. compared with 156s. 3d.; and 9·2-in. H.E. 170s. 10d. compared with 217s. 6d. The total output from the group—3,800,000 shell—had cost approximately £13,600,000 to produce, or £14,660,000 allowing for depreciation and management commission. Compared with contract rates, this showed a saving of £2,750,000, and it was estimated that this sum would meet the difference between the capital cost (calculated at £6,830,000) and the probable realisable value of the factories. On only one factory, Hackney Marshes, was there an actual loss in working, while Messrs. Beardmore's factories at Glasgow had effected a saving over contract prices sufficient to wipe out their capital cost and leave a margin.

This result was considered satisfactory for a period which included starting up and during which economy had to be subordinated to output. It could, moreover, be claimed for the factories that they had effected a further indirect saving by producing shell which would otherwise have had to be ordered at high prices in America, while their cost returns had provided valuable data for reducing contractors' prices for the larger natures of shell.

As has been seen, the capital cost of the factories was estimated in 1915 as about £7,000,000. The actual capital expenditure on the group up to 31 March 1918, amounted to approximately £7,390,000. This sum includes the cost of conversion of plant at Nottingham and Sheffield (Messrs. Hadfield's factory) which turned over to gun work at the end of 1917. The expenditure on the factory at Darlington is also included, but that on the Leeds factories and on Ailsa Craig and College Park is comprised in the total for National Shell Factories.[2] In addition, the expenditure on the Tipton Components Factory amounted to £310,800, while by 31 March 1919, £812,200 had been spent on the Ponders End factory.

[1] The figures for March, 1917 do not include Darlington; those for October, 1918, include Ailsa Craig and College Park and exclude Leeds, Nottingham and Sheffield (Hadfield's) all of which were then classed as National Ordnance Factories.

[2] *See* above p. 93.

II. Individual Projectile Factories.

Birtley National Projectile Factory.[1]

In July, 1915, Messrs. Armstrong, Whitworth undertook to erect at Birtley, near their Elswick Works, two factories, one to produce shell and the other cartridge cases. Sites were selected near the North-Eastern Railway Station, on the high road from Newcastle to Durham, and close to a colliery and a large electric power station. The area occupied by the Projectile Factory was 52 acres 3 roods; by the Cartridge Case Factory, about 9 acres. The land, which was agricultural, was taken over under the Defence of the Realm Act, but the site of the Projectile Factory was subsequently purchased, the cost being about £24,137.

An agreement on the ordinary National Projectile Factory lines was concluded with Messrs. Armstrong, but in August a novel factor was introduced, when approval was given to a suggestion that the Birtley factories should be worked by Belgian labour. Three Belgian engineers undertook to find sufficient labour to staff the factories, to make arrangements for housing, and to act themselves as joint general managers of the technical departments, responsible to Messrs. Armstrong, as the agents of the Ministry. The progress made in securing labour and in housing construction was not satisfactory, and in November a Ministry representative was appointed to take charge of the recruiting of Belgian workmen. By the end of the year it was apparent that the Belgian managers could not fulfil their bargain, and they were superseded. It was felt to be desirable, however, in order to avoid friction, that the Belgian workmen should be under Belgian control, and the Belgian Government were therefore approached on the subject of management.

An agreement between the British and Belgian Governments was signed in February, 1916. The Belgian Government undertook to manage the factory and provide labour, while the British Government were to pay all expenses, including wages, and to provide material. A British representative was to be stationed at the factory to be responsible for financial matters and for transport and to act as intermediary between the Belgian management and the Ministry of Munitions. The Belgian Government expressly desired to work in direct conjunction with the British Government, without the intervention of Messrs. Armstrong. The firm accordingly relinquished their management of the Projectile Factory, though they completed its erection and agreed to act in a consultative capacity if required. Moreover, it was decided to abandon the original project for a shell factory and a cartridge case factory under one management, and the cartridge case factory was retained by Messrs. Armstrong. It was walled off from the Projectile Factory

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[1] HIST. REC./H/1122.4/3; HIST. REC./R/400/57; M./Demob./143; (Printed) *Weekly Report, passim.*

and rented by the firm who worked it with British labour under a contract agreement.[1]

The construction of the Projectile Factory was practically complete by the end of April, 1916, but delays occurred in the delivery of machinery. The factory was in working by the end of August, 1916, save that the forging presses did not give a satisfactory output until the end of the year. The factory was laid out for 8-in. and 6-in. H.E. shell and for 60-pdr. shrapnel. Deliveries of 6-in. began in July, 1916, of 60-pdr. at the end of August, and of 8-in. in the middle of September. By February, 1917, the promised maximum output was attained for all three natures, viz.—4,000 8-in., 8,000 6-in., and 6,000 60-pdr. per week. In the spring of 1917, 4·5-in. H.E. was begun, instead of 60-pdr., but the latter was taken up again in 1918, and both natures were produced for some months. In 1918, also, 4-in. anti-aircraft shell were produced; 3·7-in. and 8-in. proof shot were undertaken; and some experimental work was done on 6-in. stream-line shell. The 2,000,000th shell made by the factory was delivered at the beginning of June, 1918. The total output of the principal types produced by the factory to the end of 1918 amounted to 2,806,800 shell, the largest output being of 6-in. H.E. (1,292,000). The output of 8-in. H.E. was 637,300; of 4·5-in. 399,300; of 60-pdr. shrapnel 461,000 and of 4-in. 16,200. Work closed down immediately after the Armistice, and all forging operations had completely stopped by the third week in November.

One of the conditions of the agreement with the Belgian Government in February, 1916, was that 1,000 skilled men should be released from the Army, and throughout a large proportion of the men employed at Birtley were of military age. There were very few women workers: in April, 1917, out of 3,708 employees only 36 were women, while in October, 1918, there were 3,826 men and no women. Day and night shifts were worked, but there was no Sunday labour. Piece work rates were as a rule paid, the rate being the normal trade union one for the work in question. At the end of 1916, a bonus on production was granted to foremen and chargemen. As there were no restrictions on output, high wages were accompanied by large output and by low costs of production. An account is given elsewhere[2] of the village which was constructed to house the Belgian workmen and their families. The repatriation of the Belgians began as soon as possible after the Armistice, and arrangements were made for 1,500 to leave England in the first week of December.

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[1] 94/National/103. A somewhat similar arrangement was made late in 1917 in connection with the scheme for a so-called "Government Cartridge Case Factory" at Long Eaton; but in this instance, the Ministry was to bear the initial cost of establishing the works, which were to be rented and operated by Messrs. Fenton Bros. at fixed contract prices, while the Ministry was to receive one-half of the profits. The project was, however, abandoned in the spring of 1918. (Printed) *Weekly Report*, No. 121, 1, p. 5.

[2] Vol. V, Part V.

The estimate of the cost of the factory given by Messrs. Armstrongs in the autumn of 1915 was higher than that of any other National Projectile Factory yet received. The firm attributed the high cost largely to the purchase of American machinery and to the provision of electric power cables from the main station to sub-stations on the site of the factory. The actual capital expenditure on the factory up to March, 1918, amounted to £892,800, including the cost of the site.

Cathcart National Projectile Factory (Messrs. G. & J. Weir).[1]

Messrs. G. & J. Weir undertook to erect and manage a National Projectile Factory at Cathcart as part of the Glasgow Shell Scheme,[2] and a suitable site was found in a grass park opposite the firm's works in Minto Avenue. The land was the property of Sir John Stirling Maxwell, and in consideration of certain moral obligations which bound him not to lease it for industrial purposes, the Ministry took over the site under the Defence of the Realm Act.

Agreements for erection and management were drawn up on the lines common to National Projectile Factories, and the firm undertook to machine 2,000 8-in. shell weekly, the forgings being supplied by the Ministry. By 5 February, 1916, the main buildings were nearly completed, though some delays occurred in obtaining the necessary electric power from the Clyde Valley Company, and the power plant was not actually completed till 3 June, 1916. By April, 1916, preliminary operations on shell were begun and the machines were being run to train the workers. In May, the factory was completing unfinished shell from Cardonald, and by 10 June, 1916, the first hundred shells were produced by the factory. A shortage of forgings hampered production in September, 1916, but the promised maximum was reached by November, and early in 1917 the average weekly output was over 3,000. After 12 May, 1917, when the total output had reached 94,200, shell manufacture ceased entirely as the factory was put at the disposal of the Controller of Aeronautical Supplies, an arrangement being made by which the plant was stored and the firm rented the factory from the Ministry in connection with their contracts for aircraft.

The equipment of the factory was retarded in April, 1916, by lack of skilled labour. The original estimate of the staff required was 45 skilled men and 500 unskilled, but in June, 1916, women were being trained, and the managers reported a serious lack of skilled men. In March, 1917, women formed 61·2 per cent. of the total employed (1,044).

The capital expenditure on the factory was very roughly estimated in September, 1915, as £105,000. The actual capital expenditure to March, 1918, was £36,100.

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[1] 94/National/47, 110. ; D.D.G.A. 21, 582 ; HIST. REC./H/1121.3/2. (Printed) *Weekly Report, passim.*

[2] Vol. II, Part II, Chap. XIII.

Darlington National Projectile Factory (North Eastern Railway Company).[1]

A factory at Darlington was taken over by the Ministry on 1 July, 1916. The factory occupied about 2 acres of land belonging to the North Eastern Railway Company, within the area of their locomotive works. Up to the date of nationalisation the North Eastern Railway Company produced 18-pdr. H.E. shell as sub-contractors to Messrs. Armstrong, Whitworth, the factory having been erected in the summer of 1915, by Messrs. Armstrong, but at government cost. The buildings and plant were therefore from the beginning the property of the Government, and the decision to nationalise the factory simplified the position of the railway company by placing them under the direct control of the Ministry of Munitions.

An agreement signed in May, 1917, by the Ministry of Munitions, the railway company, and Messrs. Armstrong provided that the Ministry should bear the entire cost of working the factory and should pay to the railway company 12½ per cent. of such cost to cover supervisory charges, this being the usual arrangement with railway companies making munitions. Rent, not exceeding 5 per cent. of the cost of the land, was to be paid for the site of the factory. The railway company were already under an obligation to take over the factory at the end of the war, if required to do so. The general intention of the agreement was stated to be that the railway company should neither make any profit nor sustain any loss.

Owing to the fact that the managing firm was a railway company this agreement had some provisions not common to national factory agreements, the type to which it most closely approximated being that for National Projectile Factories. Until the summer of 1918, the factory was generally known as a National Shell Factory, although it was not administered by the Area Organisation Department; certain negotiations being effected through the War Manufacture Sub-Committee of the Railway Executive Committee, as was the case with other railway companies. From 1 June, 1918, the factory was controlled by the section responsible for National Projectile Factories.

Up to the time of nationalisation the factory had produced 30,000 18-pdr. H.E. shells a week, but after it was taken over it changed to 18-pdr. shrapnel. Output of this varied according to requirements, beginning in the late autumn of 1916, with 8,000 a week. Early in 1917, 6-in. gun H.E. shell was also undertaken, and in the summer of 1918, the average weekly output was 18,000 18-pdr. and 1,300 6-in. The total output between the date of nationalisation and the end of 1918 was 1,063,800 18-pdr. and 116,700 6-in. Other work undertaken included the repair of fired primers, and, in 1918, the manufacture of cast iron practice shot for the Admiralty.

Foremen and skilled men were supplied by the railway company from their locomotive shops, and trained, in the early days, by Messrs. Armstrong. Unskilled labour was supplied by women, who in the

[1] Contracts/Firms. A/2224; 94/Railways/7; C.S.M. 21618; C.G.A./Misc/66; A.M.3.C./Darl. Rep. /11; A.M.3./7097.

summer of 1916 numbered about 1,400. During the interval of some months which elapsed between the cessation of H.E., and the beginning of shrapnel, manufacture, these girls were dismissed and were re-engaged as required. In the spring of 1917 only one shift, employing about 480 women was being worked, but more labour was taken on when requirements for shell increased, and in October, 1918, the employees numbered 992, of whom 813 (81·9 per cent.) were women.

The capital expenditure on the factory up to March, 1918, amounted to £106,400.

Dudley National Projectile Factory (Messrs. Bean & Sons).[1]

The land required for the National Projectile Factory at Dudley was bought from Mr. and Mrs. Bean and Mr. Edward Harper for £13,866 18s. This price included a large house which could be adapted for administrative officers. The site was on a hill to which railway access was impossible because of the steep gradient, but it was near the agent's works and was the best available. A road dividing the site was reserved for the sole use of the Ministry, and compensation was paid for damage to the town roads caused by motor transport from Dudley stations.

Messrs. Harper Sons & Bean undertook to manage the factory in accordance with the scheme initiated in July, 1915, though to distinguish between their own firm's work and the national factory, as managers of the latter they were known as Bean & Sons. In August, 1917, a thorough reorganisation of the management was successfully carried out.

On 16 August, 1915, the Ministry authorised the firm to proceed with the work and construction began. Quick progress at first produced optimistic promises, but the buildings were not actually complete till 27 May, 1916. The forging-shop, originally most advanced, had much steelwork blown down in a gale at Christmas. Machine delivery was good but erection slow though temporary power was secured from the adjoining works. The factory was planned to produce 6,000 6-in. H.E. (Mark III) and 15,000 60-pdr. shrapnel (Mark II) weekly, and this maximum was to be attained in August, 1916. In March, 1916, a contract placed with the firm for 70,000 60-pdr. shrapnel was transferred to the national factory, adding an extra temporary allocation of 2,000 weekly. Production of shrapnel shell began early in the year, the first delivery being bonded by 13 May, 1916. The output was slow at first, rising gradually from about 1,700 a week in May to an average of 10,000 in September, 1916. Work began on the 6-in. shell on 28 April, but none were bonded till the week ending 12 August. The maximum output promised of each nature was reached by 25 November, 1916. Great difficulty was experienced in starting up the forging shop, and forgings were obtained from other firms until September, 1916, when all the presses were at work. The factory did not fulfil its original intention of manufacturing its own component parts. The difficulties frequently experienced by the Ministry in providing adequate supplies of components and raw material

[1] (Printed) *Weekly Report, passim.*; HIST. REC./H/1122.4/5.

became acute at the end of 1916, and the 6-in. forges, on the verge of stopping early in December, were actually idle the first week of January, 1917. This month the promises of output were raised to 7,500 H.E. shell and 17,000 shrapnel. Throughout 1917 the 6-in. weekly output remained at about 7,000 while in January of that year an urgent Admiralty order for 4,000 6-in. chemical shells (smoke) was undertaken. Lack of components delayed their completion till after 18 May, when the factory was instructed to turn over the extra capacity to 6-in. H.E. and steel chemical shell.

Negotiations followed for a weekly output of 10,000 6-in. chemical Mark III (lethal or lachrymatory) and the first lot of this shell was bonded by 1 September, 1917. Shortage of containers prevailed till November, but the factory then turned over the entire 6-in. production from H.E. to chemical shell, aiming at 15,000 weekly. The output of 60-pdr. fluctuated between 15,000 and 18,000 till March, 1917, when part of the plant was turned over to 18-pdr. shrapnel and H.E. shell; but as great difficulty was experienced in the forging, both presses and furnaces being quite unsuitable for so small a type of shell, the programme was abandoned in September, 1917. The best weeks' deliveries of 18-pdr. shell barely reached 10 per cent. of the estimated output and from October, 1917, it was decided to concentrate on 6-in. chemical and 60-pdr. shrapnel of which the former was to be worked up to 15,000 and the latter to at least 20,000 weekly. Production of these two types increased steadily till February, 1918, when in view of the steel shortage the shrapnel output was curtailed. Through 1917, the factory had also been engaged on gun repair, and in March, 1918, some of the shrapnel plant was taken over for aero-engine work in connexion with Rolls Royce contracts. At the end of June, 1918, the factory suffered seriously from the influenza epidemic. Throughout the autumn the output remained at about 15,000 of each nature. While shell production was brought to an end towards the close of the year, 900 workers were retained on aero-engine work in 1919. The total output of 6-in. H.E. and chemical shell produced up to the end of 1918 was 980,800; of 60-pdr. shrapnel, 1,441,200; and of 18-pdr. H.E. 37,200.

Though labour trouble was not anticipated, it was a perpetual difficulty at Dudley from the beginning. Navvy labour for construction was hard to obtain as other big firms in the district paid at higher rates, and as early as 25 September, 1915, a two days strike of excavators retarded work. In January 38 soldiers were at work on erection, and in June, 1916, a military working party was employed on production. The staff required was estimated as 500 skilled, 1,500 unskilled, and 1,450 women (3,450), but lack of skilled labour was felt during the summer of 1916 and unrest prevailed in November, 1917. Of the 5,767 employees in October, 1918, 44·4 per cent. were women.

The cost of erection and equipment was estimated in August, 1915, as £332,606 but this was already much exceeded in January, 1916, when the total amount paid, including the purchase of land was £483,485. By March, 1918, the capital expenditure was £788,000.

Glasgow National Projectile Factory (Messrs. Beardmore).[1]

After the meeting of armament firms in July, 1915, Messrs. Beardmore & Company, of Glasgow, undertook to produce 4,500 9·2-in., 6,000 6-in. and 6,000 60-pdr. H.E. shells weekly from a group of three factories at Cardonald, Mossend and Mile End, controlled by them through one general manager. All the forgings were to be made at Mossend, the 9·2-in. were to be machined at Cardonald (originally known as Craigton), and the 6-in. and 60-pdr. shell at Mile End, Bridgeton. The agreements for erection and management followed the usual lines for National Projectile Factories, but in October, 1917, the firm agreed to waive any further claim to the management remuneration allowed, only charging the general manager's salary to the Ministry.

Mossend.—The land at Mossend was adjacent to Messrs. Beardmore's existing steel furnaces, and was the private property of Sir William Beardmore, who offered, first, its free use for the period of the war and a short while afterwards, and then, at the Ministry's request, a 21 years' lease at a nominal rent. Building and equipment proceeded very slowly, and no forgings were produced till the autumn of 1916, as owing to the difficulty of steel supply the Government did not press for the factory's completion. Women were employed on forging from the start, but traffic congestion and lack of material hampered the factory's development till March, 1917. In October, 1918, there were 840 employees, of whom 30·5 per cent. were women.

Cardonald.—The site at Cardonald covered 8¼ acres, and was purchased from Sir William Beardmore for £9,862. In September, 1915, the firm agreed to undertake 6,000 8-in. shells instead of the 4,500 9·2-in., and forwarded requirements accordingly. Construction was hampered by bad weather in November, 1915, and the machine-shops did not start work till the middle of March, 1916, when forgings were obtained temporarily from the North British Locomotive Works, pending Mossend's completion. In the last week of May, 1916, Cardonald sent 50 unfinished shell to Cathcart, and the first completed shell were delivered by 10 June, 1916. Output gradually increased in July, and the promised maximum was attained by 23 September, 1916. The supply of forgings was still short, and in November the factory was still being supplied from outside, though Mossend had started work. Labour was increased in December, 1916. In January, 1917, the promised maximum rate was raised to 12,000 shells weekly, and the output rose rapidly, reaching over 15,000 weekly by 17 February. In April, 1917, the revised shell programme involved reduction in the output of large-sized shell, and part of the Cardonald 8-in. capacity was turned over to produce 30,000 18-pdr. weekly. The 8-in. output dropped in May, 1917, to an average of 4,083, and by 11 August the first thousand 18-pdr. shells was bonded; but after October, 1917, the 8-in. maximum was raised to 24,000 weekly at the

[1] 94/Nat./10, 74, 131; C.R./DGSG/2398, 2549; D.F.C./C/66; (Printed) *Weekly Report, passim.*

expense of the 18-pdr. production. Until October, 1917, the factory was also undertaking gun repair at the rate of 80 18-pdr. guns monthly. In January, 1918, the 8-in. shell output was 13,348, and owing to the further change in programme, no effort was made to increase this, but the next month some 8-in. machines were adapted to produce 5,000 6-in. chemical shells weekly, while the managers were instructed to reduce the 8-in. output to 10,000. By 6 April, 1918, 6-in. cast-iron chemical shell were started, and the work improved rapidly, about 4,000 weekly being delivered in May, 1918, when the 8-in. capacity was further reduced to 5,000, and the estimated maximum of chemical shells fixed at 10,000 weekly. This output was reached in August, 1918. The total output of 8-in. shell during the war was 1,008,100, while the 6-in. chemical and 18-pdr. shells produced numbered 319,800 and 50,900 respectively.

In April, 1918, schemes were put forward to extend the factory for the building of at least 10 tanks weekly, in addition to the shell programme; but output had not been obtained before the cessation of hostilities.

The full staff of the factory was estimated in March, 1916, at 140 skilled and 1,400 unskilled men, and no difficulty seems to have been met as to labour until December, 1917, when some unrest among foremen retarded the 8-in. work. The management was a matter of more difficulty at first, and much discussion over its relation to the unsatisfactory output took place in June, 1916, but by 5 August a thorough reorganisation of the supervisory staff was completed and good results followed. Women were employed later and formed 63·3 per cent. of the total employed in October, 1918 (3,517). As both housing in the town and accommodation at the factory were most inadequate, plans were brought forward, in 1918, for extending the welfare buildings, and erecting a hostel for women, but the scheme was dropped after the Armistice.

Mile End.—For the 6-in. H.E. and 60-pdr. machine shops an existing cotton mill adjoining the Caledonian Railway at Mile End, or Bridgeton, was rented from Messrs. Grant for £1,800 per annum, plus £9,000 compensation for the removal of machinery; £7,500 was also required to strengthen the building.

Instruction in machining began during the week ending 19 February, 1916, and the next month 160 were at work on production, the ultimate staff being 140 skilled men, 20 unskilled, and 1,400 women. By 17 June 630 60-pdr. and 345 6-in. shells were bonded, and the output increased gradually through the summer, though not so rapidly as had been hoped. The promised 6,000 of each type was reached by 28 October, 1916, but in November a slight decrease in the 6-in. output attended the change over to bottled shell. In January, 1917, the estimated output was raised to 7,000 6-in. and 8,500 60-pdr., and these numbers were attained before the end of the month. In April, 1917, Mile End undertook 25,000 18-pdr. out of the 75,000 weekly then allocated to Glasgow, and the first delivery was bonded by 24 May, three months ahead of Cardonald. A steady improvement was maintained through

the summer, and in October, 1917, the maximum output possible from the 6-in. plant was reached. In February, 1918, the 18-pdr. production ceased, and the machinery turned over to 60-pdr. work. In April, 1918, a partial change over was made to 6-in. steel chemical shell, and by June, 1918, the factory was producing 10,000 6-in. H.E., 2,000 6-in. chemical, and 4,000 60-pdr. weekly. In the autumn the 6-in. plant was gradually adapted for making 60-pdr. shell, the output of which was 14,000 weekly by the end of October, when the employees numbered 2,914, 54·3 per cent. being women. The factory's total output of 6-in. shell (H.E. and chemical) was 868,800; of 60-pdr., 679,600; and of 18-pdr., 459,800. The factory closed down at the end of the year without trouble.

The estimated cost of buildings at Mossend and Cardonald was £45,660 and £86,667 respectively, but by March, 1918, the capital expenditure on the three factories was £1,107,600.

National Projectile Factory, Hackney Marshes (Messrs. Dick Kerr).[1]

The preliminary work for the National Projectile Factory at Hackney was started later than most, as the site originally chosen on Hackney Downs had to be abandoned owing to the objections raised by the London County Council to the use of park land. By 25 September, 1915, a new site was found on Hackney Marshes, and the Council granted its free use till the end of the war. Cleaning began on 15 October, 1915, and progressed rapidly; two of the four units were built by 8 January, 1916, and though delivery of machines was slow, the whole structure was complete by 26 February, 1916.

Until the forging shop was in working order the firm supplied forgings and base-plates from their own works to utilize the machines erected and train labour. Shell production began in the middle of February, 1916, and by 1 April, 324 workers were being trained, while the managers hoped to produce 4,000 shell weekly by the end of the month. Though not the first to begin shell-turning, Hackney's first few weeks' deliveries were greater than those from any other National Projectile Factory. It was laid out to produce 15,000 6-in. Mark XVI, and by May, 1916, a total of 1,771 was delivered, but after this month only Mark IV was produced. By 3 June, 1916, the output reached 1,000 weekly, but partly owing to the lack of skilled labour the rise was not as rapid as had been expected from the good start. Prolonged attempts at reorganising the management were begun, as investigation showed an inadequate development of central organisation and the employment of unsuitable labour, while the managers had no hope of reaching the full output before the end of the year. In spite of some attempts at improvement the average output for August, 1916, was only 6,449, and in November 13,300 weekly. In December, 1916, the factory's capacity was re-estimated as 16,000 weekly, and after a temporary drop due to steel shortage this number was delivered in the week ending 6 January, 1917. The next week 111 machines were idle owing to lack of steel, and when supplies of American steel were

[1] HIST. REC./H/1122.4/4; 94/National/4. (Printed) *Weekly Report, passim.*

forwarded the factory found much difficulty in forging it. The cost of the 6-in. shell, in comparison with that in other factories, was very high, and from 1 August, 1917, the Ministry took over direct control of the factory—an alternative already proposed in the summer of 1916. The new manager appointed effected some improvements, though the output remained less than was expected for the rest of the year. In October, 1917, the factory began producing 6-in. Russian shell, but from the end of the month no forgings were obtained for many weeks, while early in December, 1917, work was hindered by air raids, which also did some damage to the factory. In February, 1918, there was a good increase, and production of 6-in. chemical shell was begun ; 840 6-in. proof shot were also bonded by the end of the month, and at the beginning of March the weekly output was 13,092 6-in. H.E., 252 cast-iron chemical shell and 48 proof shot. Instructions were then given to change over 5,000 6-in. H.E. to steel chemical, so that by April a typical week's output was 16,870 shells (6-in. H.E. steel chemical and cast-iron chemical) and 1,200 proof shot. In July, 1918, the factory was also rectifying proof shell and rebanding 6-in. C.P.C. The total output of 6-in. H.E. and chemical was 1,381,700.

In spite of the excellent labour-field to hand in North-East London, the Hackney factory experienced constant labour trouble ; 300 skilled and 2,700 unskilled men were required, but no provision was made at first for the employment of women. Labour for construction was obtained with difficulty, owing to the restriction of wages to the local rate of 11¾d. per hour, while the Ponder's End factory was paying 1s. 3d., and when production began the factory required a much more skilled class of men than that supplied through the Labour Exchange. Female labour was introduced, and in June, 1916, the Ministry recommended its extension in spite of the firm's opposition. In July and August, 1916, various disputes and partial strikes occurred, and in May, 1917, Hackney was affected by the shop-stewards' strike throughout the country. In October, 1917, slackness among the workers caused a drop in output, while in January, 1918, it was reported that the decreased production on night-shifts was due to the fact that women had to stand in food queues during the day. In June, 1918, the influenza epidemic greatly reduced the output, and the dispersal of labour began on 22 November, 1918. The numbers employed in October, 1918, were 4,473, of whom 1,431 (32·5 per cent.) were women.

The capital expenditure by March, 1918, was £652,600.

Lancaster National Projectile Factory (Messrs. Vickers).[1]

On 12 August, 1915, Messrs. Vickers Ltd., completed the purchase of a very suitable site for the proposed Projectile Factory at Lancaster, and forwarded details of the building and equipment required. The land selected covered about 33 acres, lying between one of the main roads of Lancaster and the River Lune. The London and North-Western Railway Company's canal, which formed the northern boundary,

[1] Hist. Rec./H/1122.4/1.

afforded facilities for the cheap transport of coal, the same company's line passed only a short distance away, while the Midland Railway crossed the site. A good water supply was drawn from the river. The scheme followed the general lines of the agreement for National Projectile Factories, and was considerably cheaper than any others proposed. Construction estimates were very moderate owing to the satisfactory nature of the site, the ease with which materials could be conveyed and handled, and the fact that buildings were only on one floor. By 11 September the necessary preliminaries to construction were begun, but as work was repeatedly delayed by various difficulties, erection and equipment were not completed till November, 1916.

The management of the factory was at first far from satisfactory. Many changes were made in subordinate positions on the staff without effecting any great improvement, and in December, 1916, when the Ministry instituted a thorough investigation into the working of the factory, it was reported that a most undesirable state of affairs existed. Tool arrangements were inadequate, untidiness and confusion prevailed in the shops, and machinery was not being used to the best advantage; above all, a general slackness and lack of co-operation among the staff prevented real efficiency. In January, 1917, however, a new general manager was appointed, who succeeded in establishing far more satisfactory conditions. Difficulties also arose between the Ministry and Messrs. Vickers over the placing of orders for materials, components or machinery, and delays frequently occurred until October, 1916, when the Ministry issued new and definite instructions, leaving certain orders only to the discretion of the management.

The intended productive capacity of the factory was 3,500 9·2-in. H.E. shells, 6,000 6-in. H.E. shells and 6,000 60-pdr. shrapnel a week. The manufacture of shell began on 9 March, 1916, and by the end of the month 31·5 per cent. of the machinery was running, though the whole factory was not completed till the following November. In May, 1916, the first 60-pdr. shells were delivered, and in September the maximum output of 3,500 9·2-in. was reached. The 6-in. shops were behindhand, as it had been originally intended to erect them at Sheffield, but they began work in July, and in December, 1916, a change from loose head shell to bottled shell was effected. Shortage of materials and components caused serious difficulties till the end of 1916, when the completion of neighbouring plant for components rendered the locality self-contained. Early difficulties in obtaining sufficient gas from the Lancaster Corporation were overcome in 1917. A scheme for extending the factory, brought forward in January of that year, was eventually dropped.

In July, 1917, the factory undertook to manufacture 50,000 grenade mortars, in addition to their shell programme, and in September shell plant was transferred to Lancaster from the Sheffield (Hadfield's) and Nottingham factories then discontinuing shell production. Lancaster, which had formerly been doing some gun repair work, now stopped this, and from the spring of 1918 concentrated chiefly on 6-in. shell. Working conditions were disorganised by the fire at Morecambe Filling Factory on 2 and 3 October, 1917, and labour was drawn off for

salvage work. Output increased steadily throughout the spring of 1918, but was much hampered from May to July by changes in programme and by the influenza epidemic, which incapacitated about 20 per cent. of the workers. A recovery set in by the end of July, and the estimated maximum was exceeded in September. Altogether 993,900 6-in. shells (H.E. and chemical) were produced, in addition to 448,000 9·2-in., 9,600 8-in. and 589,500 60-pdr. shrapnel, making a total shell output of over 2,000,000. Work continued till the end of November, 1918, after which the employees were gradually discharged, but the factory turned over to the manufacture of aircraft bombs, which was in full swing in January, 1919; an allocation of 3,000 250 lbs. bombs was subsequently undertaken, and was completed together with 1,373 550 lbs. bombs in the following July.

The labour requirements for the factory were greatly underestimated at first, and a constant shortage prevailed. Women were employed from the beginning, but the factory suffered from lack of skilled men. By September, 1916, 4,819 men and women were employed, and in February 195 boys were added. In October, 1918, there were 8,656 employees, 47·3 per cent. being women. Some difficulties arose over the hours of women employees, and relations between the women and the management were at first unsatisfactory. No troubles arose, however, over the discharges at the end of 1918.

Though the construction estimates had been cheap, the actual capital expenditure of the factory was the largest of all National Projectile Factories, the total in March, 1918, being £1,580,200.

Nottingham National Projectile or Ordnance Factory (Messrs. Cammel, Laird).[1]

In August, 1915, the Nottingham Corporation offered the Government the free use of about 14 acres of land, between the Midland Railway and the King's Field Road, as a site for the proposed National Projectile Factory. The Corporation leased the land from private owners for £300 per annum, for the duration of the war and six months afterwards, and the lease was extended for a further period of one year, for which the Ministry was to pay rent. Before the completion of the buildings it was also found necessary for the Ministry to obtain the temporary use of an adjoining plot of land belonging to the Midland Railway Company. Possession was, therefore, taken under the Defence of the Realm Act, for the period of the war.

Construction of the buildings and railway sidings began in September, and good progress was made, power being temporarily supplied by the Corporation and Railway Company. Messrs. Cammell, Laird & Company Ltd., undertook to manage the factory for the production of 2,000 9·2-in. and 6,000 6-in. shells weekly, and refused to accept any fee for supervising erection or for management. Production began early in March, 1916, and was going well by April, though the forging shops were in advance of the machinery shops. By 22 July, 1916, the

[1] 94/Nat./141, 61, 113, 37; M.C. 16; (Printed) *Weekly Report, passim*; C.G.M. 387/3.

rated output of 9·2-in. shell was reached, and in September was exceeded by 50 per cent. The 6-in. output reached the promised maximum in October, 1916, and in January, 1917, the factory's capacity was re-estimated as 3,500 9·2-in. shells and 8,000 6-in. This programme was carried out immediately, and the 6-in. output reached nearly 10,000 by March, 1917, but from April to June of that year part of the plant was changed over to the manufacture of Italian (149 mm.) shell. From July, 1917, the 6-in. output again rose rapidly to over 13,000 weekly.

In March, 1917, as part of the general reorganisation of shell capacity, the factory began to repair 18-pdr. guns, and shortly afterwards undertook manufacture of the same gun, in addition to the shell programme. In the autumn it was decided that Nottingham should be used for gun work only, and that the shell plant should be gradually transferred to Lancaster. The factory was, therefore, classed thenceforward as a National Ordnance Factory. The production of 9·2-in. shell ceased at the end of October, 1917, but two units of the 6-in. shops remained at work through the spring of 1918, to avoid dislocation of labour during the period of setting up gun machinery. Shell production, however, had completely ceased by June, 1918, by which date the total output of 6-in. amounted to 684,300 and of 9·2-in. to 210,100.

The gun plant was originally laid out for 20 18-pdrs. (new or repaired) a week, and the total number of this type produced was 354 new and 585 repaired guns. At the end of 1917, instructions were received to turn over to the new 6-in. Mark XIX gun, and capacity for 120 guns a month was provided. The first 6-in. gun was produced in June, 1918, and by the end of October 112 had been made. Repairs of this type and of the 9·2-in. were also undertaken.

In September, 1915, Messrs. Cammell, Laird proposed to employ 1,230 women in the 6-in. shell shops, but considered it impossible for them to handle the heavier shell. The number of men required on both natures of shell was 2,538, 287 of whom were skilled. By June, 1916, 3,056 men and women were already employed, and there was a very large demand for additional labour. By the beginning of 1917 the numbers had risen to 5,835 about half (53·8 per cent.) being women.

The contract price for the buildings alone was £100,500, and the total capital expenditure by March, 1918, was £796,500.

Renfrew National Projectile Factory (Messrs. Babcock & Wilcox).[1]

As a result of the development of the Glasgow Shell Scheme[2] in August, 1915, Messrs. Babcock and Wilcox undertook to erect and manage two factories, the Ypres Factory for the production of 12-in. H.E. shell and the Aisne Factory for machining 60-pdr. shrapnel.

Ypres.—The site for the Ypres factory, covering about 6 acres next to the firm's works and connected to the same railway line as the shrapnel factory, was bought under three separate conveyances. Construction was very slow and production did not begin till late in

[1] 94/Nat./60, 66, 49, 110; D.D.G.(A.) 3190; (Printed) *Weekly Report, passim.*
[2] Vol. II, Part II, Chap. XIII.

the summer, the first delivery being in August, 1916. The factory undertook to produce 500 12-in. shell weekly, and by December, 1916, the average output was 438, while the maximum was reached by 13 January, 1917. In this month a change over was made from 12-in. to 9·2-in., of which 1,200 weekly were promised. After some early difficulties as to forging, the output of the new nature rose steadily but slowly to an average of 1,000 in August, 1917, and in November following this figure was accepted as the maximum capacity of the factory. The numbers employed at this date were 610, only 18·4 per cent. being women. In 1918, the output of shell was considerably reduced, and in the autumn of 1918 it was proposed to change over the 9·2-in. plant again to the production of 12-in., H.E. shell; but though the output of the former fell rapidly in September and October, 1918, no 12-in. shell were delivered before the Armistice. The factory's total output of 12-in. was 6,100 and of 9·2-in. 64,300. The employees in October, 1918, numbered 490, of whom about half (49·4 per cent.) were women.

Aisne.—For the shrapnel shell factory, Messrs. Babcock and Wilcox offered the Government about 10 acres, also adjoining their own works, but not immediately next the Ypres factory, at £258 10s. 0d. a year. An agreement was drawn up on the usual lines, and the firm were to have the option of buying the factory, with or without the plant, when it was no longer required by the Ministry. Construction was started in November, two or three months after most of the English National Projectile Factories, and, as in the neighbouring Ypres factory, progress was very slow, being frequently delayed by bad weather. The factory was laid out to machine 10,000 60-pdr. shrapnel shells a week, forgings being supplied under direct contract from the managing firm, who extended their existing plant at their own cost, in return for the Government's guarantee that all orders for forgings for the Aisne factory should be placed with them. Production was started by 27 May, 1916, well ahead of the 12-in. factory, but no shell were delivered until July, 1916. The output rose very slowly, only averaging 1,780 in August, 1916, while throughout 1917, it was seldom more than 5,000 weekly. In December, 1917, production was much hampered by lack of components but in 1918 a great improvement was effected, and by April, 1918, the output was above the programme, remaining at about 11,000 weekly after August, 1918. The total output to the end of 1918 was 645,700.

The chief labour difficulty at Renfrew occurred during the changes from the one nature of shell to the other, which were hampered by lack of skilled labour. Women were largely employed in the Aisne factory, the total staff required being estimated in March, 1916, as 60 skilled men and 700 women. In October, 1918, women were 80·7 per cent. of the total number (1,690). Night-shifts were started in June, 1918, and gave very good results. In 1916, only male labour was employed in the 12-in. factory, 25 out of the total 375 being skilled men.

Early in 1917 the estimated capital expenditure on the Ypres and Aisne factories was revised, as £154,927 and £119,026 respectively. By March, 1918, the actual expenditure was £165,900 and £114

Sheffield National Projectile Factory (Messrs. Firth).[1]

In September, 1915, an agreement was concluded with Messrs. Firth and with Earl Fitzwilliam for the site for a National Projectile Factory at Sheffield. Machine-shops were to be built on an area of about 13 acres at Templeborough, on the Sheffield-Rotherham road, rented from the Earl on a 21 years' lease. Railway facilities were good when once a siding had been constructed, and power was obtainable from the Sheffield and Rotherham Corporations. Messrs. Firth, of Sheffield, undertook to erect and equip the factory here along the lines laid down by the standard agreements for National Projectile Factories. The forging shop was erected on about 3¾ acres rented from Messrs. Firth, and adjacent to their own works at Tinsley. Owing to the peculiar position of the forging-shop, and particularly the difficulty of distinguishing between labour and power there and in the firm's own workshops, distinct provisions were made whereby the forging-plant was erected at government cost, but the managers ran the Tinsley shops at their own expense and with their own labour, receiving a fixed price for forgings, and in consequence a lower price for the completed shell at Templeborough. Extensions were made at State cost to the power plant at Messrs. Firth's own factory, the capital expenditure being repayable after the war. The firm agreed to produce at the new Tinsley shops forgings to be machined at the Templeborough National Projectile Factory, until the latter ceased work, or Government orders should fall below half the plant's capacity for three months When this occurred the firm were to have the option of buying any or all of the plant; otherwise the Government would be entitled, but not bound, to remove the buildings and machinery.

Constructional work began in September and proceeded so rapidly, in spite of difficulties as to labour and plant, that shell-turning began on 19 January, well ahead of any other National Projectile Factory. The ultimate output was estimated at 21,000 60-pdr. H.E. shell, and by the end of May, 1916, the weekly output reached 2,000. In January, 1917, the maximum was raised to 27,500 60-pdr. H.E. and in March an addition of 30,000 4·5-in. H.E. shells per week was made. In May, 1916, the factory began making 8,000 60-pdr. S.K. shells in place of that number of 60-pdr. H.E. None of the new type of shell was actually delivered until mid-November, 1916, after considerable difficulties arising out of the processes involved, and the factory ceased to produce them early in 1917, though in December following a consignment of 4·5-in. chemical shell was bonded. Production of the 4·5-in. H.E. shell ceased in July, 1918, when the factory concentrated on producing 60-pdr. H.E., the maximum output of which was not reached, and a small quantity of 4·5-in. chemical shell. The total output of 60-pdr. H.E. and chemical shell was 1,842,800, and of 4·5-in. 766,300.

The labour requirements for the factory had been estimated in 1915 at 300 skilled men, 1,000 unskilled and 4,000 women. Twenty women were trained on the machines as soon as shell-turning began,

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[1] 94/Nat./45, 46, 53, 57, 100, 135, 147, 150; (Printed) *Weekly Report, passim*; Hist. Rec./H/1122.4/9.

and the large percentage of women employed and trained in the factory gave excellent results. Nevertheless, difficulties in obtaining labour were frequent, although special training schools were inaugurated. In October, 1918, when there were 5,693 employees (women 87·2 per cent.), losses were reckoned at 50 weekly, and substantial improvement in output was prevented by lack of skilled labour. From 25 November, 1918, short time was worked, and the workers were gradually discharged without trouble.

The outstanding features noticeable in this factory were the effects of the establishment of two National Projectile Factories in such close proximity as Messrs. Firth's and Messrs. Hadfield's, and the close co-ordination between the new factory and Messrs. Firth's private works. Both these facts eventually proved advantageous, for central ministerial organisation solved the obvious difficulties as to local supplies of labour and materials, and the two National Projectile Factories were able to help each other in emergencies. Messrs. Firth's factory was also of great assistance, particularly in providing skilled men for purposes of "speeding-up," affording temporary supplies of urgently needed components, or undertaking necessary processes during changes of programme.

The capital expenditure had been estimated in July, 1915, at £800,000, but by March, 1918, the actual expenditure was only £661,800.

Sheffield National Projectile or Ordnance Factory (Messrs. Hadfield).[1]

In September, 1915, clearing operations began on a site selected for this National Projectile Factory, while the Ministry entered into prolonged negotiations with Messrs. Hadfield as to the rental for a lease of 21 years. The land covered about 14¾ acres, adjacent to the firm's own works; power, water and gas were readily obtainable from the Corporation, and by laying a short length of track good railway facilities with the Great Central and Sheffield District railways were secured. The site was near that of Messrs. Firth's National Projectile Factory,[2] and, later, the firm occasionally undertook urgent work for the Templeborough factory.

Two agreements for erection and equipment and for management, drawn up on the lines common to all National Projectile Factories, were made with Messrs. Hadfield. Constructional work began late in September, 1915, and after a rather slack period in December, proceeded quickly through January, 1916. By February the building was more advanced than any other National Projectile Factory still in construction, and was completed in the next month.

The factory was laid out to produce 4,000 9·2-in. H.E. shells weekly. Shell-turning began during the week ending 25 March, 1916, and by 13 May 1,500 shells were delivered in fulfilment of promises. A gradual

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[1] 94/National/73, 150, 136; D.M.A./Advances/904; C.R.V./S./42; M.C. 16; C.G.M. 387/2; (Printed) *Weekly Report, passim.*

[2] *See* above, p. 145.

increase in output continued for three months, the estimated weekly output being exceeded in August, 1916; it was maintained, in spite of some difficulties as to steel supplies, until March, 1917, the weekly output in January of that year reaching more than 5,000. The restricted shell programme of the spring of 1917 reduced production in this factory, and in May the output dropped to an average of 1,572 weekly, remaining about 2,600 till October, 1917, while the factory undertook gun-repairing at the rate of 60 60-pdrs. a month. To avoid the dual control necessitated in factories engaged in both gun and shell production, a general reorganisation was planned in September, 1917, and Messrs. Hadfield's factory changed over entirely to gun-repair, half the shell plant being exchanged for gun machinery from Lancaster, and half transferred to St Helens. By 9 February, 1918, the shell output had ceased, a total of 289,200 having been reached, and the factory undertook to repair 90 60-pdr. guns per month. Later, the manufacture of new 60-pdrs. was also undertaken, and the factory became a National Ordnance Factory, being administered by the Gun Manufacture Department.

In August, 1918, a serious shortage of coal occurred, but good progress was made on a new design of 60-pdr. gun, which was delivered to proof early in the month. The gun work undertaken included the rifling of 60-pdrs. and 8-in. from other factories. During November, 1918, the factory also bonded about 120 6-in. howitzer proof-shot weekly.

In August, 1915, the labour requirements had been estimated as 1,200 males, and in December following this was raised to 450 skilled and 1,750 unskilled men. By May, 1916, 647 men were employed and night-shifts were started, but though the labour steadily increased, no women were employed. In May, 1917, the engineers' strike reduced the production of forgings, while in June, 1918, labour difficulties again arose on the removal of men up to 20 years of age. The numbers employed at the beginning of 1917, before the factory turned over to gun work, were 2,465, and in October, 1918, 1,274.

The financial arrangements with Messrs. Hadfield were the subject of prolonged negotiation. The estimates for capital expenditure were £500,000, and the rent asked for the site was at first more than three times that considered reasonable at headquarters, while the amounts charged for providing tools and on various other accounts, gave rise to dispute in September, 1916. The actual capital expenditure by March, 1918, was £487,800.

CHAPTER V.

NATIONAL FILLING FACTORIES.

I. Introduction.[1]

The National Filling Factories were divided into three classes: those dealing with (*a*) gun ammunition, including shell, cartridges and minor components; (*b*) trench warfare ammunition, including bombs and grenades with their fuses; and (*c*) chemical shell. The largest of these classes was that for filling gun ammunition and this will be dealt with first.

(*a*) *Gun Ammunition Filling Factories.*[2]

In normal times the whole of the supplies of gun ammunition for the Navy and Army and most of the components used with it were filled or assembled at the Royal Laboratory, Woolwich. At the outbreak of the war shell filling capacity in the trade was limited to five firms, one of which had filled shell with lyddite during the South African War, while the others had from time to time supplied filled ammunition to foreign countries. One of these had filled certain experimental shell for the British Government. Greater trade capacity existed for filling fuses and minor components, but no shell-filling of any kind was undertaken by the trade until early in 1915.

In July, 1915, a conference of the various armament firms was summoned by the Ministry to discuss the means of meeting the heavy increase in the shell programme needed to supply the requirements of the army. At this meeting a definite proposal was made to build National Projectile Factories.[3] This plan was subsequently adopted as the best method of meeting the situation. The increased supply of shell which this decision implied involved an immediate increase in the filling capacity, especially as it was already becoming evident that the existing facilities for filling were not sufficient to meet the growing production of empty shell from the trade, the local groups and the National Shell Factories, nor to cope with unexpected deliveries of incomplete rounds from American and Canadian contractors. It was, therefore, decided that increased capacity should be provided by the establishment of National Filling Factories.

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[1] Hist. Rec./H/1340/1, 1520/8, 1600/9, 1122/4, 5, 6, 7, 8, 11, 30, 31, 32, 33, 35, 43, 44, 45, 46, 47; Hist. Rec./R/1320/10; 1122.3/44, 45, 46; 400/57; M.C.372; C.R./Filling/22; T.W.D./219/2.

[2] For the place taken by these factories in the general arrangements for filling, *see* also Vol. X, Part V.

[3] *See* above, p. 124.

From the point of view of work, the National Filling Factories were divided into three classes. It was intended in the summer of 1915, to establish four factories, at Leeds, at Liverpool, in Scotland (Georgetown) and at Gloucester, for filling and assembling Q.F. ammunition, either shrapnel or high explosive, and making up B.L. cartridges. Five distinct factories, at Chilwell, Morecambe, Banbury, Newburn and Otley were to be engaged entirely upon the more dangerous operation of filling heavy high explosive shell. Six factories, at Coventry, Perivale, Southwark, Hayes, Abbey Wood and Cardonald, were intended to assemble and fill various classes of gun ammunition components.

From the point of view of administration, these factories were of three types; (1) administered directly under the Ministry by a factory manager, as in the case of Chilwell, Hayes, Southwark, Banbury, and later Hereford and Gainsborough; (2) controlled by agents for the Ministry, as at Coventry, Abbey Wood, Cardonald, Morecambe and later, Pembrey; and (3) administered by local Boards of Management, as at Leeds, Liverpool, Georgetown, Gloucester and (temporarily) Perivale. These Boards were appointed by the Minister. Their members acted without remuneration or profit. They were responsible both for the erection and the operation of the Filling Factories in their district.[1] Although their establishment was a part of the general scheme of 1915 for utilizing local resources, they reported direct to the Gun Ammunition Filling authority and not to the Director of Area Organisation as the National Shell Factories did.[2] At their inception in 1915, the Boards were given entire responsibility for the internal administration of their factories. By November, 1917, individual members only of three out of the five Boards of Management continued in anything more than an advisory capacity. The fourth factory at Perivale had been taken under direct control by the Ministry in June, 1916. In the fifth, at Leeds, members of the Board retained so complete a control over the internal administration of the cartridge-filling and amatol factories, that the authority of the Gun Ammunition Filling Department was difficult to maintain in matters touching technique, finance and accounting, particularly costing, and in the provision of means for ensuring safety and the health and welfare of operatives. Uniformity in these respects was becoming more and more essential as the financial position and material resources of the country became more stringent, and as the Ministry's responsibility for safety conditions within the Government factories became more clearly defined. It was accordingly proposed in November, 1917, to take all the filling factories from Boards of Management and place them under direct control. The project was, however, abandoned in face of strong local opposition at Leeds to the abolition of a body which had so successfully constructed and equipped the filling factories, and had maintained so large an output.[3]

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[1] A.M.4/Circulars No. 4 (copy in HIST. REC./R/201).
[2] *See* above, p. 89.
[3] G.A.F. 3622; M.C. 485.

For guidance in determining the lay-out of the four Q.F. ammunition filling factories at Leeds, Liverpool, Georgetown and Gloucester, certain general principles were laid down in accordance with those which experience in constructing the same kind of building at Woolwich had shown to be desirable, while the general regulations of the Home Office regarding buildings in which explosives were handled, were also adhered to as far as conditions allowed, but with the time and space available it was admitted that it was impossible to keep strictly to this, for example, in the matter of spacing. Beyond this, full latitude was given to the architect, a member of a London firm. In most cases construction was carried out by a local firm of builders. The lay-outs of the factories at Coventry and Perivale were undertaken by an architect who had designed a somewhat similar factory at Luton. At Coventry, the building was in the hands of a firm in the neighbourhood, while the Office of Works was responsible at Perivale. At four of the factories controlled by managing directors, viz., Chilwell, Hayes, Southwark, and Banbury, the buildings were designed by the managing directors, who, in the case of Chilwell and Hayes, chose London firms to carry out the construction. Banbury was built by the Office of Works, while at Southwark the buildings required in place of those already on the site were practically supplied by the use of wooden sheds obtained in sections ready for erection. The factories which were built at Hereford and Gainsborough at a considerably later date were designed and built by the Office of Works. The lay-out and construction of the agency factories at Abbey Wood, Cardonald, Pembrey and Morecambe, were left to the contractors responsible for their administration. In the case of the factories administered by Boards of Management and by agents, where the Office of Works was not directly responsible for the construction, a member of the construction staff of that Department was appointed to co-operate with and assist the builders.

Work at the filling factories was marked by two characteristics: it was unskilled, and it was all, to a greater or less degree, according to the nature of the work, dangerous. While the first of the characteristics widened the field from which labour could be drawn beyond the limits set by the requirements of the more highly skilled engineering processes, the second confined the choice of workers to the most accurate and conscientious procurable. Work which involves the continual handling of explosive materials cannot fail to be dangerous, and no regulations, however carefully made, can do more than mitigate this danger. It can, however, be greatly enhanced by failure to carry out the regulations, by careless work, or by impatient or stupid action in an emergency. Nevertheless, daily contact with even the most dangerous substances must result in dulling the sense of risk, and it was therefore essential that, in taking on workers, only the steadiest and most careful should be selected. In the early days of the war, the workers were exposed to an additional danger from lack of knowledge as to T.N.T. poisoning. At that time little was known of the effect on the health of the constant handling of T.N.T., but immediately after the first death officially reported as due to T.N.T. poisoning the Home Office

took steps to circulate information and instructions to the medical officers at factories handling T.N.T. At the same time investigations were instituted into the causes and means of prevention of the poisoning. By January, 1918, the percentage of operatives suspended for T.N.T. sickness at the largest National Filling Factory had been reduced from 11 in August, 1916, to 1.[1]

Generally speaking, little difficulty was experienced in obtaining the large numbers of unskilled workers which were needed for these factories. Such shortage as did occur was usually attributable to extraneous circumstances, such as a deficiency of housing accommodation or great local competition for labour, as was the case at Perivale. The numbers employed in all the factories working in March, 1917, were about 82,000, of whom 81 per cent. were women. In the autumn of 1918, the employees totalled 72,000, and the percentage of women was 75.[2]

The first of the National Filling Factories to come into operation with the exception of the emergency unit at Southwark, which was filling gaines early in September, 1915, was Hayes, which began output on 30 October, 1915,[3] while Perivale followed on 1 December. Bad weather conditions and the shortage of labour held up construction at several of the factories, but by March 1916, practically all were engaged on production. At Coventry, which began output in March, further delay was caused by uncertainty as to the type of buildings and machinery to be erected, and by difficulties with regard to the railway sidings. The site for the lyddite factory at Banbury was not decided upon until December, 1915; construction began at the end of January, 1916, and output on 25 April.

During the autumn and winter of 1915–16, the treatment of amatol was more or less in the experimental stage, and the consequent uncertainty as to the plant required was partly responsible for considerable delay in erecting and starting up the factories for filling heavier natures. The whole scheme for these factories was revised in February, 1916. Otley and Newburn, where scarcely any progress had been made, and to which the filling of Q.F., instead of B.L., ammunition had been assigned, were then abandoned. Their work was transferred to new amatol factories, which were erected alongside the Q.F. ammunition factories at Leeds, Liverpool and Georgetown, and were placed under the same management as those factories.

Hereford was a later project; building there did not begin until July, 1916; and the first shell were filled in November. Hereford was the last of the new shell-filling factories to be erected and was intended as a stand-by factory. Minor filling projects materialised at later dates. The factory at Gainsborough, which was established

[1] For a full account of the measures taken *see* Vol. V, Part III, Chap. IV.

[2] The same figures (total 7,452; women 1,730) have been taken for Chilwell in each case, as no figures later than March, 1917, are available.

[3] Pembrey, which began work on 2 July, 1915, did not become a national factory until January, 1917.

at the request of the Admiralty for filling mines and sinkers, was begun in November, 1917, and began work in February, 1918. The Luton fuse-filling factory was erected during the winter of 1916–17.

A great part of the achievements of these factories consisted in the working out of new filling methods and the improvement of established methods. The mixture of ammonium nitrate and T.N.T., known as amatol, was introduced as the result of experiments by Research Department, Woolwich, about April, 1915. It was first used in the national factories in the form of block charges of 80/20 amatol, which were prepared by milling at a contractor's factory and sent to the Ordnance Factory, Woolwich, and the Q.F. ammunition factories to be put into shell. Originally it was intended that the factories which were to fill the heavier natures of shell should also employ this method, but comparative trials with some of the larger shell showed that this form of filling produced results inferior to those from direct filling into the shells by the French method. It was, therefore, decided to confine block-filling to 18-pdr. shell only and equip the factories which were to fill shell of higher calibre with plant for direct filling. The simplest method of this form of filling was melt filling with 40/60 amatol, which did not require any elaborate plant. The necessity of economy in the consumption of T.N.T., however, rendered imperative the use of a mixture with a smaller proportion of this explosive, and, as an increased proportion of ammonium nitrate rendered melt-filling impossible, it was necessary to instal pressing plant for filling the larger natures of shell. It was foreseen, however, that considerable delay must occur before the large amount of machinery required could be supplied, and, in view of the urgent demand for shell, it was decided to instal melt plant in the new units at Leeds, Liverpool and Georgetown for use until the pressing plant was ready. The lay-out at Chilwell, which was planned by Lord Chetwynd, provided from the first for pressing as well as melt filling direct into the shell, and this factory was the first to use the former method.

In July, 1916, experiments were made at Georgetown in hot-filling with amatol 80/20. The process was approved in December, 1916, and was adopted there and at other factories with melt plant, except the Ordnance Factory, Woolwich, as a general method of adapting the melt-plant buildings to fill 80/20, instead of 40/60 or 50/50 amatol.

A firing trial with shell filled at Morecambe by screw stemming was carried out in November, 1916, and further experimental work on these lines was then transferred to Liverpool. In the spring of 1917, these machines were introduced for practical purposes both at Chilwell and Liverpool. Screw-filling with hot amatol was tried in January, 1917, with a vertical machine, but by June of the same year a horizontal machine had been proved to give better results, and was substituted for the vertical one.

Shell filled with 80/20 at first gave results inferior either to those filled with 40/60 or lyddite, and much time and thought were expended on improving the quality of detonation. The following comparative

table of the results at proof in September, 1916, and September, 1917, shews the improvement achieved.

Percentage of Detonations.

—	September, 1916.	September, 1917.
Lyddite	88	99
40/60 and 50/50 Amatol	92·5	98·5
80/20 Amatol	76	99

Contemporaneously with the development and improvement in methods of shell-filling, similar work was carried out with components. One of the most urgent problems in this connection was the improvement of the No. 100 type fuse and gaine. As a result of the unsatisfactory functioning of this fuse, and the big percentage of prematures which occurred with it in the autumn of 1916, large numbers were broken down, when it was found that in many cases vital parts, such as creep springs, detent springs and centrifugal bolts were missing, while the detonators were often dirty, inadequately filled, and not properly closed. Faults were also found in the filling of the gaine, in which, in many cases, the detonator was found to be upside down. To remedy this state of affairs, investigations were made into the methods employed at the various factories, as a result of which filling operations were standardised, and the standard of inspection appreciably raised. An important improvement of method in filling detonators was the introduction of varnishing and rumbling after filling, which was applied not only to the No. 100 type fuse detonator, but to all natures, and resulted, by the end of 1917, in a very high standard being reached. Throughout the existence of the National Filling Factories the efforts of the central department were concentrated on attaining, by means of a comparison of factory methods and the standardisation of operations, an increasingly high standard of efficiency. This was greatly assisted by the establishment, in 1917, of the Standard Production Unit at Perivale, where experiments were carried out under ideal conditions, the results of which were communicated to the factory managements.

In work which involved the yearly handling of thousands of tons of explosives it was inevitable that accidents should occur. Two explosions of a disastrous nature, as well as several less serious ones, marked the history of the filling factories. The first of these took place at Morecambe, where a fire which caused a series of explosions broke out on 1 October, 1917, and continued for nearly three days and nights, during which the factory was almost totally destroyed, though, fortunately, only ten lives were lost. On 1 July, 1918, an explosion occurred in the melt house at Chilwell, which, though it caused less material damage than the Morecambe fire, resulted in 134 deaths.[1]

[1] For fuller details, *see* HIST.REC./H./1122/43, 44.

The following table shows the yearly output of the principal natures of shell filled by the National Filling Factories during the war. The figures include the output of depôts at Devonport[1] and Horley[2] which completed foreign ammunition in 1915 and 1916, but not that of Pembrey, which was nationalised in January, 1917, and stopped shell filling in the succeeding May.[3] Details of the output of individual factories will be found in Appendix III.

Nature of Shell.	1915.	1916.	1917.	1918.	Total.
18-pdr. H.E.	10,600	6,830,700	13,238,000	11,886,300	31,965,600
18-pdr. S.	63,000	8,385,300	9,660,900	9,583,000	27,692,200
18-pdr. A.A. ..	—	—	4,600	300	4,900
13-pdr. H.E. ..	—	—	19,900	420,900	440,800
3-in. 20-cwt. H.E. ..	—	—	—	114,800	114,800
6-pdr. C.P.	—	—	—	225,600	225,600
60-pdr. H.E. ..	—	975,400	2,069,100	1,686,100	4,730,600
60-pdr. S.	—	200,400	519,500	771,200	1,491,100
4·7-in. H.E. ..	—	23,300	—	—	23,300
4·5-in. H.E. ..	—	4,539,200	9,432,800	7,231,100	21,203,100
4·5-in. S.	—	16,400	15,600	—	32,000
5-in. H.E.	—	—	125,600	—	125,600
6-in. Gun H.E. ..	—	—	27,200	227,700	254,900
„ S... ..	—	—	—	104,800	104,800
6-in. How. H.E. ..	—	2,178,500	10,295,400	12,108,500	24,582,400
8-in. How. H.E. ..	—	564,200	2,153,800	1,867,000	4,585,000
9·2-in. Gun H.E. ..	—	—	—	8,900	8,900
9·2-in. How. H.E. ..	—	706,400	1,565,000	1,029,900	3,301,300
12-in. How. H.E. ..	—	49,400	95,500	73,400	218,300
15-in. H.E.	—	1,100	5,900	5,100	12,100
Grand Total ..	73,600	24,470,300	49,228,800	47,344,600	121,117,300

As will be seen from the detailed accounts of the factories, this table does not by any means represent their entire output. Five or six of the factories undertook no shell, but only components, and some millions of the latter were also filled in factories dealing with shell. The following table shows the yearly output of fuses filled at the National Filling Factories during the war. The figures given denote thousands.

Type of Fuse.	Aug. 1914 to Dec. 1915	1916.	1917.	1918.	Total.
Percussion	—	16,905·6	33,438·9	27,314·6	77,659·1
Time and Percussion or Time.	9·9	—	1,722·4	393·9	2,126·2
Base	—	—	—	14·2	14·2
Total	9·9	16,905·6	35,161·3	27,722·7	79,799·5

[1] Completed 3,057,000 18-pdr. shrapnel from abroad.
[2] Completed 4,737,100 18-pdr. shrapnel from abroad.
[3] The total output of filled shell from Pembrey, including contract deliveries, was 1,143,000 8-in., 6-in., and 4·5-in.

At the beginning of 1918, the drastic reductions made in the shell programme left several of the factories with surplus capacity. Arrangements were therefore made to utilize these for filling trench warfare ammunition and aerial bombs and charging chemical shell. Perivale received allocations for filling trench mortar bomb fuses. Hereford took over all the 50 lb. aerial bombs and Chilwell the big S.N. aerial bombs filled with amatol 70/30. Gas charging and the assembling of gas shells were assigned to Banbury and Hereford. At the end of June, the possibility of utilizing the shell filling plant at Georgetown for filling trench mortar ammunition was under discussion, but the explosion at Chilwell put this out of the question, and the Trench Warfare Filling Factories continued to be responsible for all filling of trench warfare ammunition.

(b) *Trench Warfare Filling Factories.*[1]

Like the National Filling Factories, the Trench Warfare Filling Factories[2] were planned in the summer of 1915, to provide the increased filling capacity for trench mortar ammunition then demanded by the expansion of the War Office programme. They were originally three in number, situated close to the ammonal works from which they were to draw their supplies of filling material: (1) At Erith near the Thames Ammunition Works: (2) at Denaby, Yorks, adjacent to the works of the British Westfalite Company, and, (3) at Watford, on part of a site where the Explosives Supply Department was to erect a new ammonal factory. The capacity of the Erith factory was to provide for the filling of 20,000 2-in. bombs weekly, that of Denaby for 70,000 3-in. Stokes bombs, while the capacity of the Watford factory was the same as that of Erith. The principal buildings at all three factories were completed by February, 1916, but output began some time earlier; Erith filled its first 2-in. bombs on 9 October, 1915, Watford began a week later with 3-in. Stokes bombs, and turned over to 2-in. bombs in December, when Denaby came into operation. It was at first intended that the Watford works only should be a national factory, but it was subsequently found desirable to nationalise Denaby and Erith as well. Denaby was administered by the British Westfalite Company as agents at a fixed yearly fee and a bonus on output. Watford was directly administered by the Ministry, and in January, 1916, similar arrangements were made with regard to Erith. In February, 1916, the factory of the W.E. Blake Explosives Loading Company, at Fulham, which was engaged on loading ball grenades and 3-in. Stokes bombs was also nationalised. During this month the construction began of a second factory at Watford under the same management as the first. It was intended for filling heavy trench mortar bombs.

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[1] For the place taken by these factories in the general organisation for producing trench warfare stores, *see* Vol. XI, Part I.

[2] "National Filling Factories" was the title usually given to factories for filling gun ammunition, factories where trench warfare ammunition was filled being known as "Trench Warfare Filling Factories." The two groups are distinguished thus throughout this chapter.

Constant changes of programme, as well as the development of the functions of the Trench Warfare Department of the Ministry brought corresponding modifications of the work carried out at these filling factories.

In February, 1916, the Watford factories undertook the assembling of fuses for trench mortar bombs. In May, the assembling of filled 336 lb. aerial bombs was allocated to Watford No. 2, and in September the filling of 112 lb. aerial bombs with amatol began there, and from that time onward was an important feature in the work of the factory.

During the first years of the war, trench mortar ammunition was filled with ammonal, but between January and May, 1917, this was gradually replaced by 80/20 amatol. In contrast to the method followed at the National Filling Factories, which mixed their own amatol, the amatol for trench mortar ammunition was received ready mixed at the filling factory. This prevented the adoption of hot-filling, which would have involved mixing on the spot, but as such a change would have necessitated the entire reorganisation of the factories, the idea, which had been entertained during the first four months of 1917, was abandoned in May. Machine filling, which, from the spring of 1917, was being increasingly adopted in the National Filling Factories, was not generally practicable in the Trench Warfare Filling Factories, with the exception of small time and labour-saving apparatus, owing to continual changes in design and type of the ammunition to be filled.

In May, 1918, the control of the Trench Warfare Filling Factories was transferred to the Controller of Gun Ammunition Filling and, as recorded above, part of their work in filling aerial bombs was distributed among the National Filling Factories. Proposals had already been made for relieving them of some of the filling of trench mortar bombs when the explosion at Chilwell not only made this impossible but necessitated the return of all aerial bomb-filling, with the exception of the heavy bombs filled in the melt houses at Chilwell, to the trench warfare factories. Shortly before the Armistice, however, arrangements were made for filling 6-in. trench mortar ammunition at the National Filling Factories.

In the autumn of 1918, the numbers employed at Erith, Denaby, Fulham and the two Watford factories were approximately 3,000, and of these 83 per cent. were women.

(c) *National Factories for Filling and Assembling Chemical Shell.*[1]

The completion of chemical shell by "filling," *i.e.*, by inserting the bursting-charge and by "assembling" with the fuse and cartridge was carried out partly at national factories erected or taken over for the purpose, partly at Trench Warfare Filling Factories and also, in 1918, at some of the National Filling Factories. Before June, 1916, both the filling and assembling of grenades, and later of lachrymatory shell had been carried out at a contractor's factory at Walthamstow, where the lachrymatory liquid was also charged into the projectile. This factory

[1] For the part played by these factories in the production of chemical warfare stores, *see* also Vol. XI, Part II, Chap. III.

lay in a very congested neighbourhood and in June, 1916, it was nationalised and decision was taken not to use it for the purpose of assembling lethal shell.[1] This work was temporarily undertaken at the Ordnance Factory, Woolwich. The assembling of 4-in. Stokes mortar bombs, and the filling of the gaine with ophorite was allocated to the Trench Warfare Filling Factory, Watford, No. 1. From this time (July, 1916) onwards, an increasing proportion of the capacity of this factory was devoted to the assembling of chemical bombs, while, in April, 1917, Watford, No. 2 received a weekly allocation to assemble 20,000 chemical shell. In August, 1916, the construction of a national chemical shell assembling factory was begun at Greenford in order to relieve the Ordnance Factory, Woolwich, from the dangers of leaking shells.

New arrangements were made in connection with the assembling of shells charged with mustard gas. In November, 1917, an agreement was completed with Nobel's Explosives Company Ltd., for the erection and administration of a factory for making mustard gas (H.S.) as well as for charging and filling the shell. A site was selected at Chittening and construction began in January, 1918. In the spring, owing partly to the increased production of H.S. required, it was decided to place the manufacture and the charging into shell under different authorities. The control of the charging and completion of these shells was placed in the hands of the Controller of Gun Ammunition Filling and Chittening was accordingly transferred to his department. Experimental charging began at the end of June, 1918, and by 14 July 1,000 6-in. shells had been charged. The work at Chittening was of a particularly dangerous and unpleasant nature and at one time the casualties amounted to nearly 100 per cent.

The work done by these factories and by the National Filling Factories in head-filling and assembling chemical, incendiary and smoke shell is shown in the following table.

Nature of Shell.	1916	1917	1918	Total
18-pdr. Chemical	—	—	251,600	251,600
18-pdr. Incendiary	—	—	39,000	39,000
60-pdr. Chemical	—	580,900	63,800	644,700
4·5-in. Chemical	18,000	954,700	1,230,700	2,203,400
,, Smoke	—	118,500	349,200	467,700
6-in. How. Chemical	—	49,800	1,309,000	1,358,800
Total ..	18,000	1,703,900	3,243,300	4,965,200

The gross capital expenditure to 31 March, 1918, on the National Filling Factories amounted to £10,295,000, on the Trench Warfare Filling Factories to £215,800. These figures exclude the cost of the later work entailed by converting plant at the National Filling Factories for

[1] For the account of Walthamstow, *see* below p. 184.

chemical work. The cost of Greenford and Walthamstow factories, engaged from the first on filling and assembling chemical projectiles, was £118,000 up to the end of March, 1918. The H.S. Filling Factory at Chittening was not then complete, but Treasury sanction had been received for an expenditure of £750,000. The actual cost of Chittening by March, 1919, was £57,900.

II. Individual National Filling Factories.

National Filling Factory No. 11, *Abbey Wood.*[1]

In accordance with a scheme for the erection of filling factories for minor components in the London area, the Ministry, in the middle of August, 1915, opened negotiations with the King's Norton Metal Company, a firm which had had many years experience in work of this nature.

A convenient site was selected on the company's property adjacent to their works at Abbey Wood, and construction began on 23 September, 1915. A part of the land was taken under the Defence of the Realm Act, and part by agreement with the company.

The building agreement between the Ministry and the company provided for the erection of the factory by the company on their own land at the Ministry's expense, with an additional sum paid to the company to cover equipment, establishment charges, and a fee for supervision and profit. A representative of the Office of Works was appointed to superintend and assist in the work. Under the agreement for administration, the factory was to be controlled by the company acting as agents of the Ministry on the basis of a lump annual sum, not contingent on output.

The original schedule of work to be undertaken provided for the filling of 100,000 gaines, 200,000 fuse detonators, 200,000 T tubes, 200,000 primers and between 50 and 100 tons of cartridges weekly. In April, 1916, the filling of fuse No. 100 and assembling fuses or gaines were added. Output began during the first week in January, 1916. In a typical week (ending 18 May, 1917), the number of components filled was :—primers 140,000; detonators 170,791; gaines 37,185; fuses 42,210; T tubes 40,400; cartridges 53,300. The number of fuses and gaines assembled, tape-banded, and soldered amounted to 84,529. The total number of fuses filled during the war was 161,900 of No. 100; 269,700 of No. 102; 942,800 of No. 101 B, and 2,410,400 of No. 101 and 101 E types, making a total of 3,784,800. The total number of T tubes filled amounted to 5,141,000. The output of primers was 16,015,400; of cartridges 3,640,100; and of detonators 10,608,400.

The labour employed in the factory in March, 1917, consisted of 1,624 women and 194 men. In October, 1918, the total number was 1,096 and the percentage of women 85·8 per cent.

The capital expenditure to 31 March, 1918, amounted to £116,400.

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[1] C.R./Filling/23; C.R./Filling/68; Hist. Rec./H/1340/1; Hist. Rec./R/400/57; Hist. Rec./R/1122.3/26, 63.

National Filling Factory No. 9, Banbury.[1]

The lyddite filling factory at Banbury took the place to some extent of the factory for amatol filling which had been projected near Watford, but which was abandoned owing to the unsuitability of the site.[2] After an examination of various localities in the south-west of England, a suitable site of 142 acres (afterwards increased) was found at Banbury, in December, 1915. The factory was designed by the managing director appointed by the Ministry, and the contract for building was let to a London firm.

Construction began on 28 January, 1916. The first plans provided for a capacity to fill 100 tons of lyddite into shell per week, but at the end of April, 1916, it was decided to extend the factory to include a second unit with a similar capacity to the first. The necessary plant was provided by transferring to this factory the lyddite plant ordered for Hayes, as the buildings for it in course of erection at Hayes were required for other purposes.

The first shell were filled on 25 April, 1916, and the total output to the time of the Armistice was 3,865,600 shells of various calibres. In September, 1917, a beginning was made in filling H.2 mines with ammonium perchlorate for the Admiralty and from then until 7 September, 1918, when this allocation ceased, 20,400 mines were filled. In February, 1918, the allocations for mine and lyddite shell filling were curtailed, and filling of 60-pr. and 6-in. shrapnel shell was begun. During the summer, the factory began charging, head filling and assembling chemical shells. The total output of the different natures of shell was as follows:—18-pdr. chemical 250,600; 6-pdr. C.P. 225,600; 60-pdr. H.E. 822,200; 60-pdr. shrapnel 608,600; 4·5 in. chemical 93,400; 6-in. gun shrapnel 67,000; 6-in. howitzer H.E. and chemical 1,449,900; 8-in. H.E. 16,200; 9·2-in. howitzer H.E. 332,100.

The number of workers employed at the factory in March, 1917, was 993 men and 548 women. In October, 1918, the women were 52·3 per cent. of the whole number (1,463). The capital expenditure to 31 March, 1918, amounted to £174,000.

National Filling Factory No. 12, Cardonald.[3]

Upon 9 September, 1915, it was arranged that Nobel's Explosives Company should undertake the erection and administration of a factory for filling minor components, a scheme which had been under discussion during the previous month.

A site was selected near Cardonald Station, on the Glasgow and Paisley Joint Railway, which was conveniently situated both for the supply of labour and the transport of materials. The building contract was placed with a Glasgow firm and a representative of the Office of

[1] HIST. REC./H/1340/1; HIST. REC./R/1122.3/51; HIST. REC./R/400/57; HIST. REC./R/1122.3/26; C.R./Filling/62.

[2] *See* also Hayes (p. 166, below).

[3] HIST. REC./R/1122.3/42; HIST. REC./R/400/57; HIST. REC./R/1122.3/26; HIST. REC./H/1340/1; C.R./Filling/133.

Works was appointed to supervise and collaborate in the work. Construction began on 18 October, 1915, and in spite of some delay caused by snow storms, building was practically complete by the end of the year.

The factory was designed for a filling capacity of 200,000 detonators, 150,000 primers, and 100,000 T tubes per week. Output began on 24 January, 1916, and the number of components filled between that date and the signing of the Armistice was 38,418,600 detonators of various types; 24,603,700 primers and 10,074,300 T tubes.

In March, 1917, the number employed at the factory was 747, of whom 701 were women. In October, 1918, the total number was 475 and 89·2 per cent. were women.

The capital expenditure to 31 March, 1918, was £63,500.

National Filling Factory No. 6, Chilwell.[1]

When the question of the location of the various factories to be erected for filling heavy shell was under consideration, it was agreed that the neighbourhood of Nottingham would be a convenient locality for a central shell filling factory where the empty shell from the northern and midland manufacturing centres could be intercepted on their way to the coast for embarkation. In August, 1915, Viscount Chetwynd, a director of Messrs. Vickers, Ltd., was appointed managing director of a factory in this area, which was to be the main factory for filling shell of heavy calibre. He found a site at Chilwell, five miles south-west of Nottingham. The land, which consisted of 208 acres, was taken by agreement. Lord Chetwynd was entirely responsible for the lay-out and equipment of the factory, and for its construction, which was carried out by a London firm and began in the middle of September, 1915. The factory was divided into two parts, north and south, with a road running between them. On the north side were the ammonium nitrate mill, the T.N.T. mill, the amatol mixing house, the press houses, experimental buildings, changing rooms, canteens, offices, magazine reservoir, and other smaller buildings. To the south were the ammonium nitrate shed, T.N.T. store for the T.N.T. mill, the boiler and power station, the filled shell store, the empty shell store with the melt house adjoining it, railway sidings and other buildings and stores.

The lay-out provided for a capacity for making 1,000 tons of pressed and 500 tons of melt amatol per week, and filling this amount into shell of 60-pr. calibre and upwards. Some smaller shell were filled during the first few weeks of the factory's operations, when the supply of heavier natures was not equal to the filling capacity available. The Chilwell process had the following characteristics:—the ammonium nitrate and T.N.T. were ground separately to a high degree of fineness; they were then mixed for about ten minutes in a machine which did not grind them together, and the amatol thus made was taken immediately to the press houses and used so quickly that it was actually

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[1] D.D.G.(C.)/C.M.G./336/14; D.D.G.(C.)C.M.G./336/6; C.R./Filling/299; Hist. Rec./H/1340/1; Hist. Rec./R/1122.3/26, 48; Hist. Rec./R/400/57; D.D.G.(C.)C.M.G./336/31; C.R. 2594.

warm when pressed into the shell. This enabled advantage to be taken of the change in the state of the ammonium nitrate which occurred on cooling. In contrast with this, the method adopted at other National Filling Factories consisted in grinding together for about twenty-five minutes in a gunpowder mill with heavy iron rollers comparatively small charges of rather coarse ammonium nitrate and flaked or lumpy T.N.T. This effected an "incorporation."

The first trial shell were filled in January, 1916, regular output began in February, and the factory filled a large proportion of the heavier natures of H.E. shells for the 1916 summer campaign. Screw-stemming machines for filling cold amatol were introduced in the spring of 1917, and a good deal of experimental work in connection with the development of machinery was carried out at the factory. By the end of 1918, the factory had filled a total number of 19,342,700 shells, made up as follows: 60-pdr. H.E. 3,020,100; 4·5-in. H.E. 45,000; 6-in. gun H.E. 254,900; 6-in. howitzer H.E. 11,159,200; 8-in. H.E. 2,927,000; 9·2-in. gun H.E. 8,900; 9·2-in. howitzer H.E. 1,753,000; 12-in. howitzer H.E. 162,500; 15-in. H.E. 12,100.

On 1 July, 1918, a serious explosion took place in the amatol mixing house where amatol was prepared for filling by pressing. So far as it was possible to ascertain definitely the cause of the accident, the Home Office Committee of Enquiry considered that it was probably due to the presence of a piece of machinery in one of the mixers. The number of workers killed was 134; a few were seriously injured, and a large number slightly injured. The mixing-house and its extension, and the T.N.T. mill, were completely destroyed; and the power-house buildings were severely damaged. Work was, however, resumed in the melt section on the following day, and immediate steps were taken for the reconstruction of the factory, which only ceased work upon the signing of the Armistice. Under the new lay-out, the mixing-house was to be divided into four, to reduce the possibility of damage, and the buildings were constructed of steel, for the sake of speed.

In March, 1917, the number of workers employed was 7,452, of whom 5,722 were men. The large proportion of men compared with that in many of the filling factories was due to the heavy natures of the shells filled. A certain amount of difficulty was experienced, especially in the early stages of the factory's existence, in obtaining labour of the right type.

The capital expenditure to 31 March, 1918, was £2,712,100, and a sum of £250,000 was sanctioned for reconstruction after the explosion.

National Filling Factory No. 10 *or* 21, *Coventry.*[1]

In the summer of 1915, the Ministry suggested that Messrs. White and Poppé, who owned large engineering works at Coventry, and were acting as sub-contractors to one of the great armament firms, should undertake the erection and control of a factory for filling graze fuses (No. 100). A site of some 109 acres belonging to the firm and adjacent to their own factory, was acquired by agreement, and by 23 July,

[1] Hist. Rec./R/1122.3/26, 66; 400/57. Hist. Rec./H/1320/1.

1915, the preliminary plans for a factory, with a capacity for filling 150,000 fuses, 150,000 gaines, and 300,000 detonators weekly, were ready. The building contract was placed with a local firm, but owing to difficulties with regard to the railway sidings, construction only began on 12 September, 1915, and it was not until some time later that the scheme for the railway sidings was finally settled. In addition to this cause of delay in the completion of the factory, great difficulty was experienced by the contractor in obtaining building labour. Towards the end of 1915, too, a hurricane occurred which did considerable damage to the work already done, so that it was not until March, 1916, that building was sufficiently advanced to admit of beginning output. In February, 1916, financial sanction was given for the extension of the factory to include a unit for filling time fuses, No. 80, and building began in March.

The agency agreement with Messrs. White and Poppé was based on the payment of a definite sum for each component filled, with a minimum annual sum to cover agents' fees on each unit of the factory.

By the end of September, 1916, the factory had reached a weekly output of 150,000 No. 100 fuses, 150,000 gaines, 300,000 detonators for fuse No. 100, and the same number for gaines, while in addition a certain number of T tubes was being filled. The total number of fuses filled during the war was as follows :—No. 80/44, 50,300 ; No. 80, 2,029,900 ; No. 100, 2,695,800 ; No. 106, 7,285,600 ; No. 103, 2,004,000 ; Nos. 101 and 101 E, 7,355,000 ; No. 131, 10,100 ; No. 12, 14,200 ; making a total of nearly 21½ million.

During the autumn and winter of 1916-17, numerous prematures were reported from France, a large proportion being fused with fuses filled at this factory. Similarly, prematures at gun-proof occurred with numerous fuses and gaines which had been filled at Coventry. On examination it was found that there were many cases of careless assembling, *e.g.*, detonators were found upside down. The issue of fuses and gaines filled at Coventry was stopped, and on 30 December, 1916, the use of ammunition containing fuses filled at this factory was prohibited. Further examination served to point to the fact that the 1·78-grain detonators, which were being supplied to the factory, were unduly sensitive and were to some extent the causes of the prematures. The issue of the detonators was stopped pending special tests, and the contract for them was cancelled. The factory was entirely re-organised, and on 7 February, 1917, instructions were given for all fuses and gaines filled there, prior to the reorganisation, to be emptied and re-filled. The number of the factory was then altered to F. 21, as ammunition marked F. 10 was not unnaturally regarded with suspicion by the men in the field.

In September, 1917, the supplies of filled No. 80 fuses in stock, and the capacity available for filling, rendered the continuance of the Coventry factory on this work unnecessary, and the 80 fuse-filling section was, therefore, handed over to the Controller of Aeronautical Supplies. A year later it was found that increased filling capacity for this fuse was again required, and as the factory was no longer needed for aeroplane work, it reverted to its original use.

In March, 1917, the labour employed consisted of 3,357 women and 507 men. In October, 1918, women were 90·3 per cent. of the whole number (2,780). Temporary hostels were erected for the women workers.

The capital expenditure to 31 March, 1918, was £813,400.

National Filling Factory No. 22, Gainsborough.[1]

In September, 1917, negotiations were opened between the Admiralty and the Ministry with a view to the erection and control by the Ministry of a factory for filling sinkers with T.N.T. A site of 143 acres was chosen at Gainsborough, the preliminary plans were settled by 21 November, and the Office of Works began construction three days later. The control of the factory was in the hands of a managing director appointed by the Ministry, as direct control was considered desirable in view of the secret nature of the work.

The first sinker was filled on 14 February, 1918, and four were sent to Portsmouth on 18 February. Owing to the shortage of empties, regular output did not begin until 11 March, but from that time the supply improved, and on 25 June a maximum output of 70 sinkers in 24 hours was reached. The output was then reduced to 250 per week, and later to less than 200. From the end of September, however, until the Armistice, a weekly output of 200 was maintained. At the end of August the filling of H.2 mines with ammonium perchlorate was begun, and from 7 September until 11 November the output of these was 250 per week. In September, trench howitzer bombs were sent to the factory for storage and emptying.

The total number of sinkers filled was 5,522, representing 5,547,518 lbs. of T.N.T. The number of H.2 mines filled was 2,393, containing 383,860 lbs. of ammonium perchlorate.

At the end of October, 1918, the number employed in the factory was 322, of whom 53·4 per cent. were women. The total capital expenditure to 31 March, 1918, was £52,000.

National Filling Factory No. 4, Georgetown.[2]

In the summer of 1915 the Ministry decided to erect four national Q.F. ammunition filling and assembling factories, one of which should be in Scotland. A committee[3] was appointed by the Director of Munitions for Scotland, to act as the Board of Management of the factory. Its first meeting was held on 6 September, 1915.

The site chosen for the factory was an area of about 250 acres at Fulwood, Erskine, Renfrewshire, on the main Caledonian Railway line from Glasgow to Greenock, and on the Rivers Gryfe and Dargavel.

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[1] HIST. REC./R/1122.3/41 ; C.G.A.F. 349.

[2] HIST. REC./R/1122.3/35 ; 1122.3/26, 400/57 ; D.D.G.(C) C.M.G. 334.

[3] The members of the Committee were :—W. Melville, Esq., C.E., Chief Engineer Glasgow and South Western Railway Company, J. Dalrymple, Esq., C.A., General Manager Glasgow Corporation Tramways, J. Miller, Esq., F.R.I.B.A., and R. J. Smith, Esq., C.A.

The land, which had been formerly used for agricultural purposes, was almost level, and removed from dwelling-houses, while its surroundings allowed for expansion. The district was named by Mr. Lloyd George, at the request of the Board of Management, on the occasion of his visit on 24 December, 1915. Constructional work began on 25 September, 1915.

The capacity, as intended in October, 1915, was to provide for assembling Q.F. ammunition 18-pdr. to 4·5-in. up to 40,000 rounds per week, manufacturing 200,000 B.L. cartridges and filling shells up to 60-pdr. with block charges. Later, provision was made for filling 20,000 primers per week, and the assembling of fuses and gaines was also undertaken. In February, 1916, in order to increase the capacity for shell-filling by pressing cold 80/20 amatol, arrangements were made for the erection and control of an additional unit, adjacent to the existing one, capable of (*a*) storing, mixing and incorporating 300 tons of amatol 80/20 charges, and filling weekly, on double shift, 160,000 18-pdr., 50,000 4·5-in., 15,000 60-pdr. and 15,000 6-in.; and (*b*) melting and filling 150 tons of amatol 40/60 into shell of from 4·5-in. to 8-in. calibre, and on emergency 9·2-in. The construction of this second factory was begun early in March, 1916.

At the end of January, 1916, output began with the filling of 60-pdr. cordite cartridges, and in March the first shrapnel shell were filled (18-pdr. and 4·5-in.). Block filling began early in April. The total output of the factory from March, 1916, to the end of 1918 consisted of about 19,300,000 shells, 26,842,300 cartridges, 32,472,500 components, and 11,500 6-in. trench mortar bombs. The last named were filled from July to November, 1918, only. The shell filled included Russian and Roumanian as well as star shell, the total output of the principal natures being as follows:—18-pdr. H.E., 7,986,600; 18-pdr. H.E. anti-aircraft, 4,900; 18-pdr. shrapnel, 5,093,000; 13-pdr. 9-cwt. H.E., 440,800; 3-in. 20-cwt. H.E., 114,800; 60-pdr. shrapnel, 654,300; 4·5-in. H.E., 2,898,400; 4·5-in. shrapnel, 6,400; 6-in. howitzer H.E., 2,040,400; 9·2-in. howitzer H.E., 7,700; 12-in. howitzer H.E., 45,900.

An important feature at Georgetown was the experimental work carried out in the factory. In July, 1916, experiments were made in a method of shell filling which obviated the necessity for the expensive machinery required for pressing, and at the same time was more economical than melt filling, which involved the use of at least 50 per cent. of T.N.T. By this method hot dry ammonium nitrate was mixed with molten T.N.T. in the proportion of 80/20 in a steam jacketed pan, and filled into shell by hand stemming and light malleting. Later a Hind and Lund machine was substituted for hand mixing, and the stemming was carried out by means of a light pile-driver instead of with a hand mallet. As a result of these experiments 80/20 hot mixed amatol was recommended by the Ordnance Committee in December, 1916, for general approval as a service filling. Experiments were also made in filling shell by machine, and in May, 1917, after various trials, a horizontal worm screw-filling machine was installed in the melt houses. Two others were added later, and the machine was officially

recognised as being the right type for filling by the "hot mixed" process. In 1917 also means were devised of sectioning filled shell which had been fired and recovered, in order to ascertain the effect upon the filling of the shock of discharge.

Labour was chiefly drawn from Glasgow and other neighbouring towns, but a considerable number of workers came from the Western Highlands and Islands, and also from Ireland. In March, 1917, the number employed was 12,837, consisting of 12,024 women and 813 men. In October, 1918, there were 11,344 employees, the percentage of women being 85·2. Between March, 1916, and November, 1918, five lives were lost through explosions and forty-one accidents occurred which caused serious personal injuries.

The estimated cost of construction in February, 1916, was £264,100. The actual expenditure to 31 March, 1918, owing to the extensions and developments required (including the construction and equipment of the amatol factory) was £1,368,400. The cost of working was increased by the exceptionally large area over which the factory buildings were dispersed.

National Filling Factory No. 5, Gloucester.[1]

The factory at Gloucester was one of the four Q.F. filling and assembling factories which the Ministry in the summer of 1915 decided to erect.

A Directing Board was formed[2] and began to consider plans in September. A site of 308 acres of agricultural land was selected at Quedgeley, about three miles south of Gloucester, on the west side of the Midland Railway main line, between Gloucester and Bristol. The erection of the factory began on 20 October, 1915.

The factory was originally planned to provide capacity for filling 40,000 rounds of 18-pdr. shell and 250 tons of B.L. cartridges per week, and for assembling fuses and filling these and other minor components. Production began on 13 March, 1916, and up to the time of the Armistice the total output consisted of 4,513,100 18-pdr. H.E., 5,768,900 18-pdr. shrapnel, and 384,300 4·5-in. shell filled and assembled, 17,600 60-pdr. shrapnel shell filled, 7,005,700 cartridges filled, 2,511,300 fuses assembled, 566,900 No. 106 fuses, 11,501,500 primers, 8,489,100 trotyl exploder bags and cartons filled, and 503,000 C.E. pellets compressed for fuse 106.

The women required for the work of the factory were drawn from Gloucester, Cheltenham, Stroud and neighbouring villages, and no difficulty was experienced in finding the numbers needed. The supply of male labour was a less easy matter, as the factory had to compete with several engineering works in Gloucester which were already engaged on Government work. Of the male workers employed the majority were either unfit or over age, for military service, or boys under 18. In March, 1917, the factory had on its books 720 male

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[1] HIST. REC./R/1122.3/43; 400/57; 1122.3/26.

[2] The members of the Board were: J. J. Macgregor, Esq., J. H. Beach, Esq., Harley K. Butt, Esq., and John Fielding, Esq.

employees and 5,644 women, making a total of 6,364. In October, 1918, 81·4 per cent. of the total number (6,227) were women. The first 70 women were trained for six weeks at Woolwich, the rest received their training in the factory.

The total capital expenditure to 31 March, 1918, was £410,400.

National Filling Factory No. 7, Hayes.[1]

Filling Factory No. 7 originated as one of the four factories for filling minor components situated in the London area.[2] Mr. A. C. Blyth, who at the request of the Ministry, had undertaken to look for possible sites in this area, found 200 acres of suitable land at Hayes, on the Great Western Railway from Paddington to Slough. Negotiations regarding the erection of the factory were opened on 9 September, 1915, and construction, which was placed in the hands of a London contractor, began on 18 September, 1915. Mr. Blyth, who was managing director on behalf of the Ministry at Southwark Filling Factory, received a similar appointment at Hayes, and continued to control the two factories until the Armistice.

The original designs provided for a filling capacity of 100,000 fuses, 300,000 fuse time rings, 200,000 primers, 300,000 T tubes, and 50,000 18-pdr. shell with block charges per week, as well as for filling cartridges as required and making detonators and primers. When, at the end of 1915, Southwark ceased to fill gaines, this work also was undertaken by Hayes.

In November, 1915, the managing director was instructed to arrange for the extension of the factory to include a shell-filling unit, which would supply a proportion of the capacity lost by the decision to abandon the plan of a shell filling factory at Watford.[3] This new unit was capable of manufacturing and filling into shell 200 tons of amatol per week and 100 tons of lyddite. It was laid out along the lines of the Filling Factory at Pembrey.

Production in the first factory began on 30 October, 1915, with the filling of 18-pdr. shell with block charges. In a typical week (ending 18 May, 1917), the output of filled shell and components from both units was as follows :—Shell, 31,293 ; cartridges, 89,170 ; friction tubes, 44,440 ; primers, 117,160 ; exploders, 272,000 ; detonators, 422,310 ; fuses, 177,098 ; gaines, 177,531 ; primer caps, 125,914. In addition 83,944 H.E. shell and 32,000 shrapnel were assembled ; 147,021 fuses, gaines and adapters were assembled, and 41,400 assembled fuses and gaines soldered. The total output of shell from both units up to the end of 1918 was as follows :—18-pdr. H.E., 4,977,100 ; 18-pdr. shrapnel, 1,828,200 ; 60-pdr. H.E., 86,600 ; 4·7-in. H.E., 23,300 ; 4·5-in. H.E., 4,855,400 ; 6-in. gun shrapnel, 37,800 ; 6-in. howitzer H.E., 572,400 ; 12-in. howitzer H.E., 200. The total numbers of fuses filled were 10,000

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[1] Hist. Rec. /H/1340/1 ; Hist. Rec./R/1122.3/16 ; Hist. Rec./R/1122.3/26 ; Hist. Rec./R/400/5 ; C.R./Filling/198 ; C.R./Filling/70 ; D.D.G.(C.)C.M.G.337/1 ; X235/167.

[2] *See* under Perivale (p. 173 below).

[3] *See* also under Banbury (p. 159 above).

of No. 80, 765,500 of No. 100, 5,582,800 of No. 106, 459,200 of No. 103, 1,598,500 of No. 102, and 8,315,200 of No. 101, making 16,731,200 of all types. The number of friction T tubes filled during the war was 3,864,000.

The labour employed in the factory in March, 1917, consisted of 8,780 women and 1,849 men, and in October, 1918, of 1,424 men and 8,375 women (83·3 per cent. of the whole).

The capital expenditure to 31 March, 1918, amounted to £899,000.

National Filling Factory No. 14, *Hereford.*[1]

On 20 March, 1916, the Minister sanctioned a proposal to erect a filling factory in the south-west of England, with a view to providing insurance against the loss of either Chilwell or Morecambe, the largest units for filling heavy shell. By the beginning of May of the same year, the necessity for an additional filling factory was enhanced by the increased demand for shell, and also by the fact that more picric acid was available for shell filling than there existed capacity to use it. A site of approximately 519 acres was found near Hereford by 6 June, 1916, and construction, which was undertaken on a lump sum contract to the lay-out made by the Office of Works, began on 12 July, 1916.

The control of the factory was in the hands of a managing director appointed by the Ministry.

The factory plans allowed for a filling capacity of 90,000 to 100,000 shells per week, which involved dealing with some 900 tons of explosive. Of this amount, 700 tons was to be amatol, and 200 tons picric acid. The picric section began output in November, 1916, and continued in operation until April, 1918. By that time, a marked improvement had taken place in the detonation of amatol-filled shell, and as the increasing stringency of imports made a reduction of the picric acid filling programme necessary, the section was closed down. It was re-opened in August, 1918, after the explosion at Chilwell, and continued in operation until the Armistice. The total output of filled shell from this section represented approximately 19,943,976 lbs. of picric acid.

The amatol section consisted of six units of 100 ton weekly capacity for pressed amatol 80/20 and one unit of the same capacity for hot mixed amatol. The total tonnage of explosive used in this section amounted to 5,850 tons of T.N.T. and 21,000 tons of ammonium nitrate. During the last month of the war, H.S. gas charging was undertaken and 7,200 shell were filled on behalf of the American forces.

The total output to the end of 1918 of the principal types of shell from both sections amounted to 1,000 18-pdr. chemical; 291,200 60-pdr. H.E.; 1,723,800 6-in. howitzer H.E. and chemical; 1,207,700 8-in. H.E.; 946,700 9·2-in. howitzer H.E., or a total of 4,170,400 shell.

In March, 1917, the total number of workers employed was 1,559, of whom 1,216 were women; in October, 1918, the total was 5,758,

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[1] HIST. REC./R/1122.3/57; 1122.3/55; 1340/26, 31, 46; 400/57; 1122.3/26; D.D.G.(C) C.M.G./344.

and the women numbered 3,858 (66·8 per cent.). The supply of labour was a matter of considerable difficulty, partly owing to the situation of the factory in a district where the native sources were soon exhausted, and which had little or no attraction for imported workers. The heavy and monotonous nature of the work also had a deterrent effect on workers.

The capital expenditure to 31 March, 1918, was £1,281,300.

National Filling Factory No. 1, Leeds.[1]

The Filling Factory at Barnbow, near Leeds, was the first of the four Q.F. filling and assembling factories to be initiated by the Ministry during the summer of 1915. Its erection and control were in the hands of a Directing Board.[2]

The factory was laid out on a site of 296 acres, a mile to the west of Garforth Station, on the Leeds and Selby branch of the North Eastern Railway, and 5 miles due east of Leeds. Transport facilities were thus easily available, and it was not found necessary to find local housing accommodation for the workers. The erection of the factory began on 13 September, 1915.

According to the original plans the maximum weekly output was expected to be 200 tons of B.L. cartridges, 70,000 rounds of 4·5-in. Q.F. ammunition and 160,000 rounds of 18-pdr. H.E. shrapnel filled and assembled, and 80,000 primers filled and completed. Some experimental work was done in December, 1915, and early in January a continuous output began with the making up of 60-pdr. cordite cartridges. The first shell were filled in April, 1916, with 80/20 amatol block charges. Early in the year it was decided to incorporate with No. 1 Filling Factory the amatol factory which had been planned for erection at Otley. A new unit was therefore laid out, with a capacity for incorporating and stemming into shell 300 tons weekly of 80/20 amatol and 150 tons of 40/60 amatol melt. Construction began on 8 March, and the first shell were filled in the new unit on 18 April, 1916. More than a year later, after the efficacy of the "hot mixed" method of filling had been proved, a fresh extension was built on to the melt house with the necessary equipment for this type of filling, and by August, 1918, the weekly output of filled shell from this unit had reached 50,000.

At the end of 1918 the total output of the factory since January, 1916, amounted to 9,062,800 18-pdr. H.E.; 332,300 18-pdr. shrapnel; 6,600 60-pdr. H.E.; 184,400 60-pdr. shrapnel; 13,308,600 4·5-in. H.E.; 1,675,000 6-in. howitzer H.E., or a total of 24,569,700 shell. In addition 36,150,000 B.L. cartridges were filled and some millions of minor components.

In the spring of 1916, a box factory was established on the site, where gun ammunition boxes were both manufactured and repaired,

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[1] Hist. Rec/R/1122.3/54; 11; 26; 7; X235/167; Hist. Rec./R/400/57; D.D.G.(C) C.M.G./331/11; *Fourteenth Report of Standing Committee on Causes of Explosions.*

[2] The members of the Board were Joseph Watson, Esq., The Hon. Rupert Beckett, A. G. Lupton, Esq., Bernal Bagshaw, Esq., and T. L. Taylor, Esq.

after use, for further service. A useful piece of experimental work was carried out at the shell filling factory in the reclaiming of waste amatol. By means of a special apparatus for separating and remixing the ingredients, it was found possible to reclaim an average of 10 tons of T.N.T. and 40 tons of ammonium nitrate weekly. As a result of this success, similar plants were established in other factories.

The labour required for the factory was largely drawn from Leeds, but considerable numbers came from York, Wakefield, Harrogate and other towns, as well as from many of the villages within a radius of twenty miles. The Lancashire cotton mills also provided a certain number. In March, 1917, out of a total of 13,315 workers, 12,150 were women and 1,165 men ; while in October, 1918, the total number was 8,234, and the percentage of women 86·6.

The factory was unfortunate in experiencing a serious explosion in December, 1916, when a 4·5-in. shell burst, when being fired by machine, and set off others near it. Thirty-five women lost their lives, and many were injured. Two other explosions of a less serious nature occurred, in which five lives were lost.

The capital expenditure of the factory to 31 March, 1918, amounted to £813,200. The cost of building and equipping the box factory was an additional £260.

National Filling Factory, No. 2, Liverpool.[1]

The idea of erecting a filling factory at Liverpool originated at the time of Mr. Lloyd George's visit to the city in June, 1915. Railway and shipping facilities, proximity to industrial centres manufacturing empty shells and the fact that large quantities of unfinished 18-pdr. ammunition were being received at the port from America, all conduced to make the locality a suitable one for a filling factory.

The erection and control of the factory were put into the hands of a Directing Board nominated by the Liverpool Munitions of War Committee.[2] The Board held its first meeting on 4 October, 1915, but work on the plans and other preliminary arrangements were begun in July. The site finally selected for the factory, after considerable discussion, consisted mainly of Bland Park Farm, in the parish of Sefton, close to Aintree Station, about 175 acres in extent, but with room for expansion. The ground was level, and situated close to the Lancashire and Yorkshire Railway marshalling sidings, and also to the terminus of the Liverpool Corporation Tramway. Construction began on 18 October, 1915.

According to the original plans the capacity of the factory was to provide for completing 7,000 incomplete rounds of Q.F. ammunition, and cutting and making up 33 tons of cordite into B.L. charges per

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[1] HIST. REC./H/1122.3/1, R/1122.3/50, 58, 26 ; HIST. REC./R/400/57 ; X235/167 ; D.D.G.(C) C.M.G./332.

[2] The members of the Board were Sir Benjamin Sands Johnson, Director of Johnson Bros. (Dyers) Ltd., Mr. Henry Bell Wortley, Ship Owner, of Alfred Holt and Company, Mr. Max. Muspratt, Chairman of the United Alkali Company, Ltd., and Hon. Sec. Mr. E. Cranstoun Given of Fortescue, Flannery and Given, Naval Consulting Engineers.

day, and filling 100,000 primers weekly. Work began at the end of January, 1916, when the first 8-in. howitzer cartridges were made up. In February, 1916, it was decided to extend the factory to include an amatol unit capable of mixing and stemming into shell 250 tons of amatol per week. The construction of this unit began on 10 March, and in July, 1916, it came into operation. In August, 1917, the Ministry established an experimental section at the amatol factory for improving the method of shell filling and useful work was done in the direction of machine filling both of shell and exploder bags. The total amount of finished ammunition was 5,426,000 18-pdr. H.E.; 6,875,700 18-pdr. shrapnel; 39,000 18-pdr. incendiary; 386,000 60-pdr. H.E.; 26,200 60-pdr. shrapnel, 95,700 4·5-in. H.E.; 25,600 4·5-in. shrapnel; 125,600 5-in. H.E.; 4,214,900 6-in. howitzer H.E.; 125,400 8-in. H.E., or a total number of 17,340,100 shells of various natures, while 24,000 tons of amatol and 1,000 tons of smoke mixture were made, 180,000,000 exploder bags, 2,500,000 exploder containers and 2,000,000 smoke bags were filled. In addition to these, 16,588,200 cartridges, 3,364,800 fuses and gaines were assembled, 291,900 No. 106 fuses, and 9,594,700 primers were filled.

The labour employed in the factory came from Liverpool, Wallasey, Ormskirk, and other places on the Lancashire and Yorkshire Electric Railway. In March, 1917, out of a total of 10,837 workers, 10,340 were women and 497 men. On 23 July, 1918, three lives were lost owing to the explosion of a 6-in. shell. In August, 1918, there were 8,599 employees, of whom 87·1 per cent. were women.

The total expenditure on the Q.F. and amatol factories to 31 March, 1918, was £725,400.

National Fuse Filling Factory, Luton.[1]

In the middle of 1916, Messrs. George Kent, Ltd., of Luton, undertook to erect and manage a factory for filling the No. 80 fuse. The site selected was at Chaul End, near Luton, where the firm had already erected a factory for fuse manufacture, and where additional land was available for the national factory.

By an agreement signed on 10 January, 1917, Messrs. Kent undertook to erect and equip, at government expense, buildings for filling fuses and for soldering and testing metal covers. To cover the cost of the fuse filling buildings, not more than £37,400 was to be paid to the firm, and in addition 2½ per cent. of the expenditure on the fees of architects, superintending engineers, etc. A further sum, which ultimately amounted to about £2,000, was to be allowed in respect of buildings and plant for soldering covers. The buildings and plant were to be the property of the Minister of Munitions, but the firm had an option to purchase them after the war.[2] The Ministry

[1] D.D.G.(C)/C.M.4/1547,Sec./Gen./1047.

[2] If the option were not exercised, the Ministry had the right to remove the buildings and plant, but should they not do so within a period of six months, the buildings and equipment would become the property of the firm. After the Armistice, the firm did not exercise their option to purchase, and the Ministry, not wishing to remove the buildings, purchased the site.

were to be responsible for expenditure on upkeep and repair and were to bear all costs of production, including wages, such costs to be ascertained quarterly. They were also to supply empty fuses and certain other materials. Delivery of filled fuses was to begin by 21 February, 1917, and to rise as quickly as possible to 50,000 per week. The agreement provided for a management fee, to be based on production costs, increasing as the cost decreased, but in no case exceeding 1¼d. for each fuse which passed inspection. Subsequently, however, the firm decided not to accept any management fee.

It was intended that the buildings should be completed and equipped by the end of January, 1917, but the time limit was considerably exceeded, largely owing to lack of building labour, and constructional work was not completed until the summer. In order to reduce expenditure, the original scheme of construction was modified, and the re-arrangement involved a reduction of filling capacity from 50,000 to 40,000 fuses a week. On 1 March, 1918, an explosion occurred, as a result of which portions of the factory had to be rebuilt and certain structural additions and alterations made to meet Home Office requirements, the estimated cost being £1,800. Extensions were undertaken from time to time, the most considerable being the erection of a magazine and mixing room, for which an expenditure of £2,420 was sanctioned in July, 1918.

In addition to filling No. 80 fuses, the factory undertook in October, 1917, to convert the No. 180 fuse to No. 80, working up to an output of 20,000 a week as soon as possible.

The employees numbered about 600, of whom over 90 per cent. were women.

National Filling Factory, No. 13, Morecambe.[1]

Negotiations with Messrs. Vickers regarding the erection and administration of a filling factory began in August, 1915. A site was found at White Lund, halfway between Lancaster and Morecambe, and thus conveniently placed for receiving empty shell from the projectile factory at Lancaster and other centres on the north-west coast, and for dealing with the heavy shell imported on the Mersey. Some 250 acres of land formerly used for grazing purposes were taken over under the Defence of the Realm Act. The building contract was placed by Messrs. Vickers with a Glasgow firm, on the basis of a percentage on prime cost, and construction began on 23 November, 1915. The agency agreement with Messrs. Vickers provided for the payment to the firm of a percentage on the net cost of building and equipment, and of a lump annual sum for the administration of the factory. Very considerable delays experienced in construction and starting up were attributed by the firm to the general uncertainty as to lay-out, since it was not until January, 1916, that the final decision as to the method of filling was given. Output began, ultimately, in July, 1916.

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[1] HIST. REC./R/1122.3/38; 1122.3/19; 400/57; 1122.3/26; HIST. REC./H/1340/1; D.D.G.(C)/C.M.G./343/1; D.D.G.(C)/C.M.G./343/2; C.R./Filling/321.

The buildings, of which by far the larger proportions were of wood roofed with felt, consisted of six danger units, 16 bonded stores (the property of the Army Ordnance Department), a paint shop, an empty shell store, stores and magazines, general offices and canteen, power station and workshop. This lay-out gave capacity for filling 500 tons pressed or 200 tons melted amatol weekly into shells of 60-pdr. to 12-in. calibre. The total number of shells filled up to October, 1917, was 2,893,100, made up as follows:—60-pdr. H.E. 117,900; 6-in. howitzer H.E., 2,195,000; 8-in. H.E., 308,700; 9·2-in. howitzer H.E., 261,800; 12-in. howitzer H.E., 9,700. On 1 October, a disastrous fire broke out at about 10.30 p.m., on the upper floor of one of the melt plants. Fortunately, the workers had not returned from supper, so that the number of casualties—10 were killed and a few seriously injured—was small compared with the material destruction caused. Numerous explosions occurred, the last of which took place about 4 a.m., on 3 October, 1917, and by 8 a.m. on the following day the factory was almost entirely destroyed. By that time practically nothing was left except the filled shell stores, which the efforts of the fire brigades had been concentrated on saving, the paint shed, the explosives magazines and part of the power house. The cause of the original fire was not discovered. Just before the close of hostilities, the factory site was utilized for chemical filling and assembling, on account of its isolation and extent.

Labour was difficult to obtain in competition with local munition works, particularly on account of T.N.T. poisoning and low rates of pay compared with those for other work. A premium bonus system was introduced to overcome this last difficulty. In March, 1917, 1,225 men and 2,248 women were employed, and in September, there were 4,621 employees, of whom 2,957 (64·4 per cent.) were women. House-room was found for the workers under the arrangements made by Messrs. Vickers for housing their operatives at the Lancaster Projectile Factory.

The capital expenditure to 31 March, 1918, was £199,900.

National Filling Factory, No. 18, *Pembrey.*[1]

In May, 1915, a contract was made by the War Office with Nobel's Explosives Company for the construction at Pembrey, of a factory for the production of T.N.T. Under this contract, Nobel's were to provide a sufficient and suitable site for the erection of loading plant adjoining the T.N.T. plant. This loading factory was to be erected and equipped by the Explosives Loading Company, for filling shells, mines and torpedoes under contract. In consequence of the decision to take over the explosives factory at Pembrey,[2] the loading factory was also nationalised as from 1 January, 1917, and the Explosives Loading Company became the agents of the Ministry of Munitions for its administration. The site was held under lease from free-holders at an annual rental.

[1] Hist. Rec./R/1122.3/49; 1124/6; 1122.7/12; 1122.3/26; 400/57.

[2] *See* above, p. 69.

The amount of H.E. which the factory was required to fill into shell was originally 100 tons per week, but this was later increased, and before the factory ceased this type of work the consumption of H.E. exceeded 200 tons weekly. The explosive at first allocated to the factory was purified T.N.T., but owing to the increasing need for economy in this material, amatol 40/60 was substituted for it.

Filling began on 2 July, 1915, and between that date and May, 1917, 1,143,000 shell sizes 8-in., 6-in. and 4·5-in. were filled. In May, 1917, the factory discontinued filling, and undertook the breaking down of defective ammunition and the recovery of components. Two amatol recovery units, each with a capacity for dealing with 50 tons weekly were installed, and from May, 1917, to December, 1918, 1,664,000 complete rounds of 18-pdr. and 13-pdr. H.E. were broken down, besides H.E. shell from 15-in. calibre downwards, shrapnel shell and aerial bombs and other forms of defective ammunition. In addition, 3,000,000 fuses, separated from their gaines, were disassembled.

The labour for the factory was at first supplied locally, but as the requirements increased workers were recruited from greater distances. The provision of special trains to and from Swansea and Carmarthen obviated the necessity for finding housing accommodation in the locality. In March, 1917, the numbers employed in the factory were 480 men and 570 women, making a total of 1,050. In October, 1918, there were 1,441 employees, 70·5 per cent. being women.

The capital expenditure on the factory to 31 March, 1918, amounted to £102,300.

National Filling Factory, No. 3, Perivale.[1]

Perivale was the first of the National Filling Factories for minor components projected in the London area, during the summer of 1915, with a view to filling empty components arriving from overseas. Its erection was arranged for by the Metropolitan Munitions Committee, at the Ministry's request, early in August, 1915, the site being inspected on 17 August. The site chosen was one of 120 acres at Park Royal in the Urban District of Acton. Construction began on 26 August, 1915. The administration of the factory was in the hands of a sub-committee[2] of the Metropolitan Munitions Committee until 30 June, 1916; from that date the operative side was directly controlled by the Ministry, but the Metropolitan Munitions Committee continued to be responsible for construction and equipment.

The factory was designed for a filling capacity of 200,000 fuses, 200,000 gaines, and 400,000 detonators per week. Later, friction "T" tubes and primers were included among the components filled. Output began on 1 December, 1915. By the middle of 1917, the number of components filled weekly had reached 1,800,000, in addition to

[1] HIST. REC./R/1122.3/37; HIST. REC./H/1121.27/1; 1340/1; HIST. REC./R/400/57; 1122.3/26; D.D.G.(C)/C.M.G./333/1; HIST. REC./R/1320/10.

[2] The Sub-committee included Mr. F. Bailey, Mr. T. H. Restler, Mr. B. Hall Blythe, and a representative of the Ministry, Capt. C. L. Conacher, later, Mr. A. Ross.

which 120,000 fuses and gaines were being soldered into cylinders per week, for despatch overseas. The total output of filled fuses during the war was 28,078,900, made up as follows:—No. 100, 3,001,200; No. 106, 5,360,500; No. 103, 2,553,600; No. 102, 1,063,200; No. 101, 16,100,400. The total number of "T" tubes filled was 5,541,500.

In August, 1917, the Ministry established an experimental unit at the factory for the production of components under ideal conditions, with a view to improving the general standard of production. Elaborate tests were carried out and the information gained was communicated to all factories engaged on similar work. In the first quarter of 1918, the unit filled 5,300 fuses of No. 101 type, and during the second half of the year, 3,000 of No. 106 were filled.

Considerable difficulty was at first experienced in obtaining a sufficient supply of labour, and it was found necessary to send out women, who had been trained in the factory, to various towns to hold meetings and recruit workers. In March, 1917, the total number employed was 5,241, of whom 4,845 were women. In October, 1918, the total number was 2,198, and the number of women 1,956 (88·9 per cent.).

The capital expenditure to 31 March, 1918, was £519,600, exclusive of £3,200 for the Standard Production Unit.

National Filling Factory, No. 8, Southwark.[1]

The component filling factory at Southwark was established as an emergency factory in the late summer of 1915. An offer was made by a firm in Southwark to place the two upper storeys of a large warehouse in Sumner Street, at the disposal of the Ministry, but as a considerable number of workpeople were employed on the lower floors the use of the upper floors for handling explosives was regarded as too dangerous. A vacant site, however, of some 60,000 square yards was found adjacent to this building, and was considered suitable for filling the small components which were then urgently required. The land was unoccupied and its title in dispute. Possession was taken on 27 August, 1915, and construction began on 1 September under the personal supervision of Mr. A. C. Blyth, who controlled both this factory and the Hayes National Filling Factory on behalf of the Ministry. Some buildings were already standing when the property was taken, and the whole factory was in working order in from fifteen to twenty days. In ten days from the date when building began the filling of gaines started, in order to meet the serious deficiency in the supply of these components. Regular output started on 1 October. In December, 1915, gaine filling with tetryl ceased in view of its danger and the congested nature of the district. The factory was intended to deal with all classes of components in emergency, and was laid out for assembling 5,000 No. 100 fuses weekly as well as detonators, primers, etc. The amount of explosive which it was necessary to keep in store for these components at any one time was so small that it could not be regarded as dangerous to the population of the district. The factory's total output of filled fuses was 8,856,800, made up of 2,035,900

[1] HIST. REC./H/1340/1; HIST. REC./R/400/57; 1122.3/26; C.R./Filling/43, 74.

of No. 100; 1,201,200 of No. 103; 681,000 of No. 102; and 4,938,700 of No. 101. In the spring of 1918, all filling operations ceased in this factory, and in April, 1918, it was transferred to the Anti-Gas Authorities as an inspection depôt for protective clothing. Later still it was used for storing the Ministry archives.

In March, 1917, the employees numbered 912, of whom 801 were women. The numbers gradually decreased, and in February, 1918 they were 381, with 335 women (87·7 per cent.).

The capital expenditure to 31 March, 1918, was £41,100.

III. Individual Trench Warfare Filling Factories.[1]

Trench Warfare Filling Factory, Denaby.

A factory for filling 3-in. Stokes bombs was built on a seven-acre site adjacent to the ammonal factory of the British Westfalite Company at Denaby, near Rotherham, co. Yorks. The land was leasehold of the company, and the buildings were erected at Government cost to plans agreed between the company and the Department, the actual orders being placed by the company's representative. Constructional work began about the middle of August, 1915, and the original buildings, except certain storage sheds and a changing room, were completed by mid-February, 1916. Additional land was taken up in the following March to meet the extended Stokes bomb programme, and the new buildings, consisting of ten filling sheds, were completed by the following July.

The method of administration was under discussion between the Department and the company between August and December, 1915. The contract price asked per box of three bombs was at first 3s. 6d., afterwards 1s. 9d. From 1 January, 1916, the factory was nationalised under an agency agreement, the company accepting £250 to cover all supervisory duties up to that date. Under the final agreement, which was dated 24 May, 1916, and was retrospective, the company undertook to fill 3-in. Stokes bombs at a fixed yearly fee and a bonus of £1 per thousand bombs satisfactorily filled. The Minister defrayed the cost of production including labour, light, heat, transport and material except the explosive, which was charged to the agents at a fixed rate. The buildings and equipment were to be the property of the State until twelve months after the termination of the war or the determination of the contract, which ever should be the later. The agreement was thus very similar to that for agency shell-filling factories; but an important variation was introduced at the instance of the company, whereby the Minister indemnified them, not only against loss by fire or under the Employers' Liability and Workmen's Compensation Acts, but also against loss of profit and damage at their adjacent explosive factory arising out of any accident at the national factory. The labour was controlled by the agents, but the Minister had power to dismiss workers or vary the rate of wages, and a technical representative of the department was resident at the factory.

[1] For the authorities on which these accounts are based, *see* HIST. REC./H/1600/9.

The factory was laid out to fill 75,000 3-in. Stokes bombs weekly, serving as a centre for the empty bombs made in the northern counties. In January, 1917, a clearing-house for these bombs was established at Rotherham to prevent congestion at the factory, where they were loaded and packed into boxes with their components ready for direct issue overseas. Filling began in small quantities on 11 December, 1915, on a large scale 29 January, 1916. In June, 1916, work was stopped temporarily on account of congestion due to lack of delivery instructions. In the following August it was decreased by half, special arrangements in reducing hours of work being made to enable the maximum output to be re-established. This was done in the following August, and in the spring of 1917 a weekly output of 90,000 was reached without introducing night-shifts. At this time this factory was the sole source of supply for bombs of this nature. In April, 1917, work was entirely suspended for a few days during a change-over in the design of bomb. It was subsequently partly occupied in disassembling obsolete 3·7-in. trench mortar bombs. Filling of 3-in. Stokes bombs was gradually resumed in June, 1917, and output rose to 110,000 weekly by the end of August. Arrangements were then made to increase the capacity still further in order to fill bombs for the Allies. This was done without incurring additional capital expenditure, and the factory continued loading 3-in. Stokes bombs until the termination of hostilities.

Several improvements in methods of filling originated in this factory. Early in 1916 a new steel drift was introduced, and in January, 1917, a novel pattern of filling bench was installed which reduced the loose ammonal to a minimum. The filling was done entirely by hand. The weekly average of workers employed during 1916 was 359, during 1917, 405. By far the greater number were women, and in May, 1917, the transport arrangements were reorganised to enable 27 men to be replaced by women.

Denaby was regarded as a peculiarly successful factory, both in economy and efficiency. The capital expenditure was estimated in February, 1916, at £6,000; in December, 1917, at £13,066. The actual expenditure down to 31 March, 1918, was £14,710.

Trench Warfare Filling Factory, Erith.

The Erith factory for filling 2-in. trench mortar bombs was built on grazing land adjacent to the Thames Ammunition Works on the Crayford Marshes. It covered an area of 14 acres and was two miles from Slades Green Station, from which a siding was laid. The buildings were partly adapted from packing sheds and magazines belonging to the Thames Ammunition Works, partly erected at state cost. The filling station proper was on leasehold land of that company; the receiving and distributing sheds were on the adjacent leasehold of an interned Austrian, which was taken under the Defence of the Realm Act. Instructions were given to the Thames Ammunition Company for the erection of the factory on 21 August, 1915, and the filling sheds were completed by the end of the following January. There were eighteen sheds in all.

An agreement with the Thames Ammunition Works for operating the factory was under discussion between August, 1915, and the following January. The alternatives proposed were :—(1) The Minister to rent the site and bear the cost of construction, the contractor filling the bombs at a flat rate and paying a nominal rent for the buildings ; or (2) the firm to fill on a cost plus percentage basis ; or (3) (suggested in December, 1915) an agency agreement similar to the Denaby agreement and to cover filling operations only, the receiving and distributing station to be directly controlled by the Department. From 27 January, 1916, the factory was taken over under the Defence of the Realm Act, owing to the failure to come to reasonable terms with the contractor and the receipt of adverse reports on the general conditions, particularly as regarded danger regulations and female labour.

Throughout the war the factory was engaged in filling ammunition for the standard medium mortar. Work on 2-in. bombs began in the week ending 2 October, 1915. In the following January the factory undertook the entire filling programme for this nature. It was originally laid out for 20,000 bombs weekly and was extended to deal with 25,000 in April, 1917, when output had already exceeded 20,000 owing to the high efficiency attained. In May, 1917, the lay-out was reorganised for filling 6-in. trench mortar bombs instead of 2-in., the filling of which was entirely transferred to Watford No. 1 in the September following. Gravity conveyors were installed for handling the heavier 6-in. bombs. Filling of this nature began at the end of May, 1917, and continued until the termination of hostilities. The total output of 2-in. bombs was 1,142,806, and of 6-in. bombs 1,063,193. It was decided in June, 1917, that no further extensions would be practicable in view of the difficulty in obtaining labour.

The district was sparsely inhabited and labour only available from a distance and in competition with many other munitions works. Workers were brought by motor transport and later by rail when the siding was completed. Canteens provided breakfast, dinner and tea. The average weekly number of employees in 1916 was 350 ; in 1917, 400. Five-sixths were women, the remaining sixth, men. A flat time-rate was paid with a bonus on the quantity filled. The high piece-rates at Woolwich drew away considerable numbers, so that the whole *personnel* of the factory was changed about once in every three months.

The capital expenditure was estimated at £24,000 in February, 1916, at £35,042 in December, 1917. The actual expenditure down to 31 March, 1918, was £42,041.

Trench Warfare Filling Factory, Fulham.

In August, 1915, W. E. Blake, building contractor, agreed to erect a factory for grenade filling. He formed a special company, the W. E. Blake Explosives Loading Company, for the purpose, and built the factory on three acres of waste ground at Stevenage Road, Fulham, on the south bank of the Thames, obtaining a lease of the site from the Ecclesiastical Commissioners. It was adjacent to Mr. Blake's grenade factory and lay in the midst of a very crowded district. The magazines were established at a distance on disused playing fields at Worm Holt

Farm, Shepherd's Bush. Transport was organised by barge to Deptford and thence by rail to Newhaven.

The factory was originally built for loading 80,000 Ball grenades weekly, and the filling of Ball, Mills, and other types of grenades was carried on under contract until January, 1916. A scheme for converting the factory to a station for filling 3-in. Stokes ammunition was initiated in October, 1915, and experimental work on these bombs began on 21 October. In the following December negotiations with the contractor for continuing bomb-filling under an agency agreement fell through. Shortly afterwards adverse reports were received as to safety conditions and accommodation for workers. In view of these facts and the failure to come to reasonable terms the factory was nationalised under the Defence of the Realm Act as from 11 February, 1916. By that date grenade-filling had been transferred elsewhere. During February and March the factory was reconstructed and reorganised, and was the first to load 100,000 3-in. Stokes bombs in a single week. In June, 1916, this work was reduced to 50,000 weekly owing to the accumulation of filled bombs. In the September following it was again decreased to 23,000 weekly, and from January, 1917, the loading of these bombs was gradually transferred to Denaby.

The factory began pyrotechnic work in June, 1916, with the filling of flares. By the following January a record standard of efficiency had been reached, and the first 1,110,000 were completed by 24 February, 1917, when work began on another million. These were finished by the end of March. Plant for filling and assembling Véry signal cartridges was installed in April, 1917; output began within three weeks, and by mid-June experiments had led to the improvement of manufacturing methods with a corresponding increase in production.

Grenade filling began again in November, 1916, and eventually became the leading work of the factory. Pneumatic apparatus was invented for filling Mills grenades and the plant was installed in December, 1916, reducing the labour employed on this work by 90 per cent. and the cost by £2 per 1,000. This machine enabled a single girl worker to obtain a record of 6,000 grenades filled in a nine-hour day. Grenade-filling continued until the Armistice, six different kinds being handled while the factory was under national control.

Miscellaneous work upon minor components began with the filling of Stokes propellant rings in August, 1916, and the assembling of Midgeley fuses for aerial bombs in November, 1916. The factory also undertook a considerable amount of experiment, such as the filling of bombs and grenades with amatol to test its suitability in these stores and the adaptation of the 3-in. Stokes bomb for incendiary purposes. The introduction of economical methods at Fulham enabled contract prices to be reduced. Thus, a comparison of costs in the manufacture of cordite rings enabled flat rates to be established with a saving of £2 10s. per 1,000. The miscellaneous character of the work is illustrated by a week's output in September, 1918, which included three types of grenade, five of pyrotechnics, experimental bomb-filling, the manufacture of cordite rings, quick-match and ignition papers and the breaking down of charges.

The local labour supply was ample and day shifts only were worked. The proportion of women to men was 15 to one. A flat rate was always paid. The average number employed weekly in 1916 was 485, in 1917 462, and in 1918 it was still below 500. A canteen was opened under arrangement with the Central Control Board in May, 1916.

The estimated capital expenditure in December, 1917, was £16,860. The actual expenditure down to 31 March, 1918, was £19,684, being limited to the lowest amount possible in view of the temporary character of the factory.

Trench Warfare Filling Factory, Watford No. 1.

This factory was built on 20 acres of agricultural land at Balmoral Road, about two miles from Watford Junction. It was adjacent to the national factory for the manufacture of ammonal, erected at Watford by the Explosives Supply Department. It occupied part of the site taken over under the Defence of the Realm Act for that factory. The project for the filling factory dated from 3 September, 1915. The lay-out was partly based on the Woolwich and Erith bomb-filling shops; the building were necessarily scattered, owing to the existence of a "pot-hole" in the middle of the site. General authority for the expenditure was obtained by the Trench Warfare Department about 4 October, 1915. The original buildings, consisting of about 19 sheds, were completed by the second week in February, 1916. From the first the factory was directly controlled by the department, and was managed by a superintendent, a volunteer, who afterwards took responsibility also for Watford Factory No. 2.

The factory was intended to load 2-in. trench howitzer bombs with ammonal from the neighbouring explosives factory, and to pack the filled bombs with their components for issue overseas. Work began on 16 October, 1915, with the filling of 3-in. Stokes bombs, which was undertaken temporarily, and ceased on 8 January, 1916. The maximum output of 2-in. bombs obtained was 20,000 weekly. The filling of this nature began on 20 December, 1915, and continued until the second week in January, 1917. It was then suspended for seven months, during which 2-in. bombs were filled at Erith only. It recommenced on 7 July, 1917, and from the end of the following September all 2-in. ammunition was filled here until the change over to 6-in. bombs took place at the end of the year. The examination and assembling of fuses began in the second week of March, 1916, and new assembling rooms were completed for this purpose early in May. From April, 1916, till the following August the filling of first deliveries of 9·45-in. bombs was undertaken, pending the construction of Watford No. 2 Factory. Work on assembling chemical, incendiary, and smoke bombs began with experimental lots of 4-in. Stokes bombs in the second week of May, 1916, and reached a commercial scale at the end of July. In July, 1916, special sheds, partitioned by hempen rope mantlets, were erected for the particularly dangerous operations of filling ophorite gaines for chemical bombs, and filling 2-in. bombs with thermit. Additions were made to these sheds during the first six months of 1917, when the greater part of the capacity of

the factory was concentrated upon these operations. Some work was also done in filling the exploders of 6-in. artillery shells filled with chemicals. In January, 1917, the factory began assembling components for the 9·45-in. ammunition, and in the following April it undertook the entire assembling of components for 3-in. Stokes bombs made in the London district.

The total number employed in November, 1915, was 39, of whom 22 were men. In 1916 the weekly average of employees was 360, in 1917, 450. Originally these were drawn from the surrounding districts, in competition with the other industries of Hertfordshire and Middlesex. Dilution eased the situation in 1916 and 1917. By the end of 1916 the women employed were 236 and men 110, and in the following March women replaced men on trolley work. Canteens, clubs, and a crèche were organised for the two factories. In the spring of 1917 the female labour of the district was exhausted, and railway fares up to 3s. weekly were allowed to overseers from outlying districts. In September, 1917, workers were brought in from Norwich. The establishment of the Greenford chemical shell factory drew away workers, and in March, 1918, the number of employees at both factories was only 30 per cent. of that needed. The situation was again met by importing labour from the provinces.

The expenditure on the original buildings was estimated in February, 1916, at £15,000. By the end of 1917 the estimate was raised to £40,487, and the actual outlay on land, buildings and plant, down to 31 March, 1918, was £40,306.

Trench Warfare Filling Factory, Watford No. 2.

This factory was built for filling heavy trench mortar ammunition early in 1916. It occupied about 40 acres of agricultural land, taken under the Defence of the Realm Act, at "Callowland," Bushey Mill Lane, Watford. Sites had previously been examined at the Sabulite Factory, Ware, and at Reading. A preliminary scheme for transporting the explosive direct from the Watford ammonal factory was abandoned, in view of its cost, in favour of an extension of the sidings at Watford No. 1. When an amatol bursting charge was substituted for ammonal, it was still arranged that mixing should take place at the explosives factory and not at the place of filling, as was the normal arrangement in shell-filling factories.

Constructional work was carried out under the Office of Works, by contract on a lump sum basis. The site was surveyed on 22 January, 1916, building began on 19 February, and 26 filling sheds were finished by the end of March. The completion of water supply and sanitary arrangements was delayed till June. A magazine, with a capacity of 250 to 300 tons, was built in that month.

The factory was controlled directly by the Trench Warfare Supply Department, and was under the same management as Watford No. 1 (*q.v.*). It was laid out for filling 20,000 bombs weekly, and in April, 1917, was extended to deal with 25,000. Since the filling programme for 9·45-in. bombs never reached the number anticipated the capacity of the factory was otherwise occupied. In addition to undertaking

the entire 9·45-in. filling programme, upon which work began at the end of May, 1916, the factory filled and assembled trench mortar fuses from June, 1916, onwards, and also fermanganised the cast-iron fuse-bodies upon special plant, completed in October, 1916. The assembling of aerial bombs began in mid-June, 1916, and in the following January the actual filling of these bombs was undertaken. In April, 1917, a scheme was started for assembling chemical artillery shell, in order to avoid erecting a special building for the purpose. The factory concentrated upon this work during a period of urgency in the early summer of 1917, but these operations ceased with the extension of the Greenford Chemical Shell Factory. From March, 1917, onwards gaines for the Livens projector drums were filled in large quantities, both for British and American use. The loading of Pippin rifle grenades began in the following May, 1917, and about 340,000 of these were filled here. In May, 1917, the work of the factory was reduced by 50 per cent., pending a decision as to its continued use for assembling chemical shell. Almost every class of work undertaken was again increased in the following July.

The labour conditions resembled those at Watford No. 1 (*q.v.*). The capital expenditure was estimated in February, 1916, at £65,000; in December, 1917, at £86,965. The actual capital cost, including land, buildings and plant, down to 31 March, 1918, was £99,050.

IV. Individual Factories for the Filling and Assembling of Chemical Shell.

National Filling Factory, No. 23, *Chittening.*[1]

The demand for shell filled with mustard gas (H.S.) was first made about September, 1917. The Ministry then entered into an agreement with Nobel's Explosives Company, Ltd., under which the latter were to design and run a factory for the manufacture of H.S. by the thio-glycol method and for the charging and filling of the shell. The lay-out was undertaken in November, 1917, the site selected at Chittening, and construction began under contract with Messrs. Thorburn in January, 1918. During the spring of 1918 arrangements for H.S. production were greatly extended, and the control of poison gas manufacture and its charging into shell ceased to be united in one authority. To avoid dual responsibility in a single factory the work of charging and head-filling was undertaken at Chittening while manufacture was transferred to Avonmouth.[2] Under the new arrangements the Chittening factory was to be controlled directly by the Controller of Gun Ammunition Filling, and, after negotiation with Messrs. Nobel's, the construction contract was accordingly transferred to the Ministry, who appointed a director to supervise its completion.

The site consisted of some 200 acres of lowlying level ground bounded on the south and west by the Great Western Railway, and on the north by the main road to Bristol, and construction

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[1] C.R./Filling/297, 319, 324, 377, 379; HIST. REC./R/1340/33, 34; HIST. REC./R/1122.3/40.

[2] See above, p. 49.

was pressed on with speed. H.S. was a dangerous liquid producing serious physiological and psychological effects on workers who were either touched with the liquid or inhaled the vapour given off by it. The peculiar difficulties involved in dealing with such a material gave rise to serious problems as to plant and ventilation, but, owing to the urgency of the demand, attention was concentrated on output, and arrangements were made to start on emergency lines, before complete provision was made for the safe and efficient handling of the liquid and for the destruction of exposed H.S., whether in the form of spills or leakages of liquid or of escaped vapour. The period of production was thus divided into three stages :—(1) That in which Nobel's charging machines were used without mechanical ventilation to destroy fumes ; (2) when a system of fan ventilation protected workers inside the charging rooms at the expense of those outside ; and (3) when new and adequate machines and ventilation were installed. The factory was laid out for charging and filling 52,000 6-in. shells, 34,000 4·5-in. and 100,000 18-pdr., but work was actually carried on only with 6-in. shell. Fourteen units were set up to charge the liquid into the shells, which were then passed on to be filled with the bursting charge of fumyl. Except for a small regular delivery from Messrs. Levinstein, of Manchester, the whole of the H.S. was conveyed from Avonmouth in tank wagons.

The first consignment came from Messrs. Levinstein about the end of June, 1918, and experimental charging was immediately begun at Chittening. In July supplies began to arrive from Avonmouth, and it was feared that charging would not keep pace with the production of H.S., but by 14 July 1,000 6-in. shells had been charged and all the available H.S. used. During the week ending 26 July 10,920 lbs. of H.S. were received and dealt with, improvements to the ventilation were planned, and it was decided to instal vacuum machines in place of the gravity type designed by Nobel's. Owing to the urgent need of immediate output on an extremely large scale, work began as construction proceeded, but was frequently suspended owing to the shortage and inferior quality of the H.S. Thus from 28 July the factory was held up for a fortnight, and again in August 15 machines, capable of charging 3,000 6-in. shell per day, were standing idle. By 29 August three units were at work, the output for July and August being 3,801 and 3,835 shells respectively. The output increased with the improvements gradually evolved, and in September 18,215 shells were charged, while in October, when the first vacuum machines were set up, output rose to 59,573. By this time charging was well ahead of gas production. Early in November the factory was again idle, owing to serious difficulties at Avonmouth which cut off the supply of H.S., and after the Armistice all chemical charging was abandoned. The total number of shells filled up to the end of 1918 was 86,400.

Some of the most difficult problems encountered by the management were connected with the question of labour, as the need for protection against the harmful effects of the gas and the treatment of workers affected were matters requiring the closest attention. Owing to the urgent demands of the service, practically all other considera-

tions were sacrificed to output, with the result that work was carried on under very bad conditions. The whole work of charging being new, difficulties had to be solved almost entirely from experience, which was not obtained without ill effects on the workers. While construction was still in progress and the welfare arrangements were scarcely yet established, temporary plant was set up, and consequently, although for so dangerous a process operatives needed to be unusually well trained, the majority were incapacitated as soon as the training was completed. In spite of the many efforts perpetually made by the authorities to ensure protection, at one time workers actually engaged on charging had nearly 100 per cent. casualties, while for a considerable period one casualty was reported for every six to nine shells that left the factory. Workers on head filling also became infected by the charged shell which were splashed, but the worst effects were felt by the fitters who had to work on contaminated machines. For most of the summer all medical and welfare work was carried on in improvised buildings intended for other purposes, the elaborate surgery being completed after the Armistice. Experience proved that healthy girls were more resistant than many of the available men, who were generally less fit, and practically all the charging was done by female labour. Owing to the irregularity of H.S. supplies night shifts had to be worked to make up for time lost when no gas was delivered. On 19 August, 1918, 230 women, 210 men and 110 skilled trade staff were at work, but it was calculated that to reach the estimated output, the unskilled labour would have to be increased to 1,000, exclusive of the replacement of casualties.

The actual capital expenditure, 31 March, 1919, amounted to £57,900.

The Chemical Shell Assembling Station, Greenford.[1]

When in the spring of 1916, the use of lethal artillery shell was approved, it was at first decided to assemble the charged shells with their bursters, either in the National Filling Factories for H.E. shell, or at the Royal Laboratory, Woolwich, in order to make use of factories accustomed to the handling of explosives. The first instalments of lethal shell were accordingly assembled at Woolwich, but actual experience with leaky shells emphasised the risks of handling projectiles filled with chemicals, and it was arranged that a separate assembling station should be established by the Chemical Warfare Section of the Trench Warfare Supply Department.

The factory was located at Greenford, Middlesex. The site, which was agricultural land, leased by the Purax Company from the Ecclesiastical Commissioners, was taken under the Defence of the Realm Act, and structural work was undertaken by the Office of Works. Construction began in August, 1916, and the initial project was completed in the following February. In March, 1917, arrangements were made to double the capacity in order to meet the increased demand for chemical shells. The factory was administered by a superintendent, under the direct control of the Chemical Section of the Trench Warfare Supply Department, until the spring of 1918, when

[1] Hist. Rec./H/1690/9; T.W.5923.

its administration was transferred to the Controller of Gun Ammunition Filling.

Operations began in January, 1917, and the factory was thenceforward responsible for assembling practically the whole of the output of lethal shells until a part of this work was undertaken by the National Filling Factories and by Chittening in 1918. Facilities were provided for experimental work, and labour-saving devices were installed during the spring of 1917.

Considerable difficulty was experienced in obtaining operatives. When the factory started up in the first week of January, 1917, there were 590 workers on the books; a year later there were over 1,000. Special arrangements were made for the transport of workers, and at one time volunteers were brought from the Trench Warfare Filling Factory at Erith, where work was being reduced.

The capital expenditure on the factory to the end of March, 1918, was £109,900.

H.M. Factory, Walthamstow.[1]

The national factory for charging and assembling chemical projectiles at Black Horse Lane, Walthamstow, was originally erected by contractors, Messrs. Baird and Tatlock, in July and August, 1915. They then undertook to charge and assemble lachrymatory grenades in the new factory, which they set up on waste land next their "Duroglass" works, where the glass containers for the chemicals were being made. In March, 1916, extensions were made to enable the factory to charge and assemble lachrymatory shell, for which purpose skilled labour had been retained at the factory during the previous winter. Progress was not entirely satisfactory, and the works were nationalised under an agency agreement as from the week ending 10 June, 1916. In November, 1917, direct control over the factory was taken by the Chemical Section of the Trench Warfare Supply Department.

The factory was engaged in charging and assembling various types of lachrymatory grenades from August, 1915, onwards. In February and March, 1916, respectively, work began upon charging and assembling 4·5-in. and 60-pdr. lachrymatory shells. Thenceforward the main work done was the assembling of various classes of lachrymatory shells, and special arrangements were made in July, 1917, for charging 6-in. lachrymatory shells. When the use of chemical grenades was revived in 1917, the factory resumed the charging and assembling of these grenades. It also undertook a considerable amount of salvage work in the summer of 1918, emptying lethal trench mortar bombs and re-charging the mixture into Livens projector drums.

Special precautions were taken to lessen the risks from lachrymatory liquids, and medical attendance was provided. The workers averaged 250 weekly during 1917, and were mostly women. A special staff of women was maintained to deal with transport, since the factory was situated about a mile from the nearest railway station. Much of the building work in connection with extensions, such as stores and experimental plant, was effected by the employees in the factory.

The total capital expenditure to March, 1919, was £9,900.

[1] T.W./Contract/351, 1594, 1881; Hist. Rec./H/1122.7/13.

CHAPTER VI.

GOVERNMENT FACTORIES FOR CARTRIDGES AND SMALL ARMS AMMUNITION.

I. Introduction.

(a) *The Government Cartridge Factories.*[1]

By far the most important of the national factories which were established for processes connected with the production of small arms ammunition were the Government Cartridge Factories initiated in the spring of 1916 to meet increased requirements. Early in the year the demand was raised to 150,000,000 cartridges weekly, and as existing organisations were already developed to their utmost ability, State manufacture was practically essential to cope with the new programme. Plans were accordingly made to provide for a weekly output of 30,000,000 rounds of ·303-in. Mark VII from State factories. One of these, to produce 6,000,000 rounds, was established at Woolwich under the control of the Chief Superintendent of Ordnance Factories, and its history belongs to that of the Arsenal,[2] but the others were operated as agency factories by various cartridge-making firms.

Negotiations began in March, 1916, with the heads of firms, and three companies undertook to manage factories in the neighbourhood of their own works. The Birmingham Metal and Munitions Company agreed to manage works at Blackheath, Staffs., known as G.C.F.1, for 12,000,000 rounds; the King's Norton Metal Company undertook a second at Blackpole, which became G.C.F.3, and Messrs. Eley Brothers erected G.C.F.4 on ground adjoining their own works at Edmonton, in North London. These two, and the Woolwich factory, undertook 6,000,000 rounds apiece. The Woolwich factory was known as G.C.F.2.

The management agreements made with the three firms were identical in each case as regards the broad outlines, though specific details varied according to circumstances. The companies, acting as agents for the Ministry, purchased the necessary land and erected and equipped the factories, receiving as remuneration a fixed percentage of the cost of construction. The plant remained the property of the Ministry, from, or through, whom all materials were to be bought, and the Ministry might alter the type of ammunition to be made, paying any cost involved in the change. All cost of production was borne by the Ministry, and the firms received a management fee covering the wages of all employees above and including the rank of foreman, and a bonus on

[1] *See* also Vol. XI, Part VI.

[2] *See* above, Chap. I.

economical working which varied with the price of materials and the rate of wages. The companies appointed and trained the necessary staff, and were not to be held responsible for delays or reductions in output due to causes beyond their control. The Ministry might at any time give notice to terminate the agreement on payment of compensation. After the war the firms were to be entitled, and under certain conditions bound, to continue as managers if the Government required their services; they were also to have the option within a certain period of purchasing land, buildings and machinery at 5 per cent. less than any other offer, if the Ministry wished to sell. The formal agreements were not signed until May and June, 1917, but construction began in the spring of 1916. In July, 1916, while erection was proceeding the small arms ammunition programme was revised and it was decided, in view of Russian requirements, that the capacity of the new factories should be halved and that they should produce 15,000,000 rounds of 7·62 mm. ammunition instead of the ·303-in. originally intended. This involved alterations in plant and delayed the equipment of all the factories except Messrs. Eley's at Edmonton, which was not sufficiently advanced to be affected. In January, 1917, as part of a general reduction in the programme, the output originally planned was reduced by half in each case, and in May, 1917, the firms opened negotiations with a view to amending the financial clauses in the agreement, which these subsequent changes in programme had rendered less favourable to them.

Possession of suitable sites had been taken under the Defence of the Realm Act in the summer of 1916, and construction began immediately. Constructional work was somewhat delayed by the severity of the winter and by difficulties in getting machines and labour. The first of the four factories began operations before the end of 1916. Cups were supplied by the Government Rolling Mills, Southampton, and after initial difficulties were overcome two of the three agency factories exceeded their estimated output in 1917. In 1918, these two factories and the Woolwich factory were changed over to the manufacture of ·303-in. cartridges, and by July the two agency factories were producing between them more than the 15,000,000 rounds formerly allocated among the four factories. The third agency factory was taken over by the Air Board for aero-engine repair work.

The factories were all confronted with similar difficulties, particularly the failure or delays of building and machinery contractors and the scarcity of labour. All were situated in towns where competition for labour was intense, but the peculiar advantages enjoyed by the state factories in the way of building and plant enabled them to effect dilution to a greater extent than any trade firm. The proportion of skilled labour to the whole was, on an average 9 per cent., and women formed a large part of the unskilled labour. At the end of 1917, when the employees in the three factories numbered 5,900, the percentage of female labour was 40·4; in October, 1918, when two factories only were working, there were 6,700 workers and 5,500 (81·5 per cent.) were women.

The original estimate sanctioned by the Treasury for the four factories was £1,539,000, including the £26,000 which was required for the acquisition of land for the three agency factories. The actual capital expenditure on the three agency factories to 31 March, 1918, amounted to approximately £966,000, while about £231,300 was expended on Woolwich.[1]

(*b*) *Miscellaneous Factories for Processes connected with Small Arms Ammunition.*

Detailed accounts are given below of two other national factories which were established in connexion with the supply of small arms ammunition. These were the Coundon Factory for filling a special type of bullet, and the Government Mills at Southampton, which were set up for the rolling of brass and cupro-nickel strip.

Two other establishments were directly controlled by the Non-Ferrous Metals Department of the Ministry during the year 1918. The one was a manufacturing warehouse at No. 50, Porter Street, Sheffield, which was originally engaged upon manufacturing processes in connexion with cupro-nickel ingots for small arms ammunition and also with brass discs for quick firing gun ammunition. With the reduction in the small arms ammunition programme early in 1918, manufacture ceased at these premises, but they were utilized as a store and also as offices for a casting shop. This was a shop originally owned by Messrs. Kent Smith, Ltd., in Bacon Lane, Sheffield. It was taken over by the Ministry as from 15 April, 1918, with a view to improving the general supervision and management. The shop was engaged in making bullets out of specially treated strip-metal by a novel electrical process. It was finally closed down in the summer of 1919. In the meantime, the premises in Porter Street had again been used, when the small arms ammunition programme was increased in September, 1918. They were then reorganised for cropping and inspecting cupro-nickel ingots.[2] By March, 1918, the capital expenditure on the premises in Porter Street amounted to £731, and on the casting shop to £1,200.

II. Individual Government Cartridge Factories.

Blackheath Government Cartridge Factory—G.C.F.1. (Birmingham Metal & Munitions Company).[3]

On the establishment of the Government Cartridge Factories early in 1916, the Birmingham Metal and Munitions Company undertook to manage a factory for the production of 12,000,000 rounds of ·303-in. Mark VII weekly. An agreement was drawn up on the lines common

[1] The figure given for Woolwich is to 31 December, 1917, the latest available.
[2] D.F.2/N.F./K/14,18.
[3] HIST. REC./H/1440/3; HIST. REC./R/400/57; D.D.G.E./E.M.2/1363, 1218, 1891, 882, 1429, 1542, 1048, 1601, 1579.

to the three new cartridge factories, and in accordance with the change of programme of 1916-17 the firm agreed to manufacture 6,000,000 a week of 7·62 mm.

A site was found for the factory at Blackheath, Staffs., most of which was owned by Sir Charles Holcroft. Before June, 1916, possession was taken under the Defence of the Realm Act, and subsequently the total purchase price for the site, including compensation to tenants, was estimated at £10,000. Instructions to proceed with arrangements had been given to the company in March, 1916, and the buildings were considerably ahead of the other two factories, being sufficiently forward for two units of machinery to be installed by December, 1916, though some difficulty was experienced in obtaining water power and light. Special pumping arrangements had to be made for water supply, and the electric power obtained from the local supply company was not very satisfactory. Much of the machinery was supplied by Messrs. Greenwood & Batley, who had a large order for the Russian Government for plant which could not be shipped across during the winter, and was accordingly diverted to the Government Cartridge Factories. Operations began at Blackheath before Christmas, 1916, although the factory was held up in December by lack of cups, due partly to a shortage of copper, and partly to delays in submitting designs. By February, 1917, four units were practically in position, though delay was caused by the non-appearance of loading machines, which were not completely delivered until December, 1917. Difficulties also developed in making a satisfactory bullet, and when these were overcome others arose in the necking process of the case, so that in October, 1917, bullets were 5 or 6 millions ahead of cases. Output of the Russian ammunition therefore, rose very slowly, and though it had been estimated that the maximum would be reached in October, the actual deliveries did not then reach 5,000,000 weekly. In November, 1917, however, the output averaged 6,176,500, the highest delivery attained by the factory in this type of ammunition. In February, 1918, the factory changed over to ·303-in. at the rate of 4,000,000 weekly, and it was laid down that further deliveries of 7·62 mm. should not exceed a total of 14,000,000. To economise material an interchange of 7·62 mm. components was arranged with Messrs. Kynochs, to balance cases and bullets. From April, 1918, a special effort was made to increase the ·303-in. output which reached 7,000,000 weekly in August, though rejections on inspection amounted to 10 per cent. Futher projects brought forward to increase the output to 9,000,000 did not materialise before the Armistice, after which production of new ammunition ceased entirely by 14 December, only 9,916,159 having been delivered since 20 November. Rectification of rejected ammunition continued till the end of the month, and in 1919 the factory was taken over by the Central Stores Department.

Dilution of labour was not carried out so extensively as at Blackpole, though the factory compared well in this respect with any trade firm. The proportion of skilled men employed in 1917 was 10 per cent., while in the tool room 63 per cent. were women and boys.

Throughout the summer of 1918 there was an urgent demand for labour, and in October, 1918, 3,491 workers were employed, of whom 3,026 (86·7 per cent.) were women. When the agreement was drawn up the estimated cost of construction was £330,000. By March, 1917, this was raised to £380,000, exclusive of the architects' fee and the fee payable to the agents, which amounted to about £21,400. The actual capital expenditure by 31 March, 1918, was £392,000.

Blackpole Government Cartridge Factory—G.C.F.3. (King's Norton Metal Company).[1]

In March, 1916, the King's Norton Metal Company undertook to manage a factory at Blackpole, Worcestershire, for the production of 6,000,000 ·303-in. Mark VII a week.

The site selected at Blackpole covered 67¼ acres, of which 51 were owned by Wall's trustees, and the rest by Lord Hindlip. Possession was taken under the Defence of the Realm Regulations, and in August, 1916, £7,000 was paid as a fair purchase price for the property. A neighbouring canal afforded water supplies, and power and light were obtainable from the local company. The buildings at Blackpole were practically complete by February, 1917, and production began at the end of the month.

In accordance with the revised programme the factory undertook to produce 3,000,000 rounds of 7·62 mm. ammunition a week, and in June, 1917, the actual output was nearly 2,000,000, which was not only an exceptionally good output as regards quantity, but excellent in quality, there being no rejections by the Inspection Department from the first large delivery. Though the factory started production considerably later than the first Government Cartridge Factory, it reached its full output much more quickly, as by October, 1917, it was producing the allotted 3,000,000 weekly, working only on a day shift. In December, the output of 7·62 mm. from all factories was reduced and at the beginning of this month Blackpole began making ·303-in. By the end of the year production of 7·62-mm. had ceased in this factory; though the last consignment did not pass inspection until February, 1918. In January, 1918, ·303-in. bullets and cases were produced separately at the rate of 3,000,000 weekly but difficulty was experienced in loading, until in February a partial night shift was put on to work off accumulation. This resulted in a delivery of 3,500,000 almost at once. At the end of February, 1918, the maximum was raised to 4,000,000 and the factory was speeded up to its utmost capacity on day and night work, till the weekly output reached 9,000,000 by 29 July, and the total amount of ·303-in. delivered up to 24 August, 1918, was 192,418,550. After the Armistice three months notice was given to the factories to close down, and instructions were issued that no more virgin copper, spelter or nickel should be used. A gradual decrease in output followed during the rest of the year.

[1] HIST. REC./H/1440/3; HIST. REC./R/400/57; D.D.G.E./E.M.2/882, 1363, 1077, 1218, 1429, 1114, 1430, 1863, 1721.

The good output from this factory was largely due to its excellent management, which was most satisfactory throughout its history. There were few changes on the staff, careful organisation by the authorities and good co-operation on the part of the employees, while the bullets turned out were considered " some of the best in the trade."

Dilution of labour was carried out to the full. In May, 1917, 4 per cent. of the employees were skilled men and 82 per cent. women and boys, while in October, 1918, of 3,235 employees, 2,462 (76·1 per cent.) were women. In the toolroom 78 per cent. of the work was done by women and boys, though at first the skilled toolroom men were opposed to female labour. In April, 1918, the factory was sending out urgent demands for labour to provide the great increase required in production.

In the spring of 1916, the estimated cost of the factory was £227,000. The change over from Russian ammunition to ·303-in. involved an expenditure of £5,000, and in January, 1918, a fresh estimate amounted to £284,122 including the £7,000 paid for the land. The actual capital expenditure to 31 March was £289,800.

Edmonton Government Cartridge Factory—G.C.F.4. *(Messrs. Eley Brothers).*[1]

In the spring of 1916, Messrs. Eley Brothers undertook to erect and manage a factory at Edmonton in accordance with the new scheme for Government Cartridge Factories. An agreement was drawn up, as for the other factories similarly established,[2] but a special clause was added in this case, in view of the firm's position with regard to their existing contracts. Messrs. Eley were producing 2,000,000 cartridges weekly in their own factory on plant paid for by a Government advance, not yet fully repaid. They then paid up the balance of this loan, becoming owners of the plant, which was purchased by the Ministry for the new factory. All the firm's small arms ammunition manufacture was thus to be concentrated in the government factory as soon as it was ready, the standing contract with the firm being cancelled. It was also agreed that the Ministry should buy certain materials from the firm.

An area of 13 acres adjoining the company's own works, and owned by the Great Eastern Railway Company and others, was selected as a site for the factory. Possession was taken before June, 1916, under the Defence of the Realm Act, and the property was subsequently valued at £9,000. There was considerable delay in the erection of the factory. Construction did not begin until August, 1916, and was hampered by various occurrences, including air-raids, so that by February, 1917, installation of machinery was only just begun. Under the revised programme of January, 1917, the factory undertook 3,000,000 weekly of 7·62-mm. ammunition, but work had not been entirely transferred

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[1] Hist. Rec./H/1440/3; D.D.G.E./E.M.2/1218, 1363, 882, 1081, 1622, 813, 1429, 1430, 1781.

[2] *See* above p. 185.

to the government factory even by December, 1917, when the combined output from the old and new factories only averaged 1,788,000 weekly, though the quality was good. The managers hoped to reach the maximum in January, 1918, and the rounds accepted by the Inspection Department in February and March numbered 23,415,225, a figure which gives a weekly average of over 2,900,000. Early in 1918 the requirements of 7·62-mm. dropped, and while the other Government Cartridge Factories turned over to ·303-in. ammunition, the Edmonton factory ceased production entirely at the end of March, and was taken over by the Air Board for aero-engine repair work.

The factory had comparatively little difficulty in obtaining labour. The proportion of skilled labour was 14 per cent. of the whole, but the management was hampered in diluting toolroom labour by an agreement made by Messrs. Eley with the Amalgamated Society of Engineers that women should only be employed there on repetition work. In January, 1918, however, there were 1,493 employees, and the women numbered 1,161, 77·8 per cent. of the whole.

In December, 1917, the estimated capital expenditure was £302,976. The total capital expenditure on the factory up to 31 March, 1918, was £284,200.

III. The National Small Arms Ammunition Factory, Coundon (Coventry).[1]

In the summer of 1917 when, among various special types of ammunition, the R.T.S. incendiary bullet was developed to meet the requirements of the Royal Flying Corps, Machine Gun Corps and Home Defence, the Ministry decided to establish a special national factory at Coundon, near Coventry, to deal with the filling of this ammunition. As the chief considerations were great secrecy and immediate output, it was necessary to have a factory entirely under government control, and if possible to utilize existing premises. Certain buildings on land belonging to Mr. J. F. Buckingham were, therefore, purchased and extended, and the surrounding land, belonging to the Coventry Corporation, was also acquired under the Defence of the Realm Act, though as this was to be used after the war for municipal purposes, only temporary buildings were erected there. Some land originally taken was later released for purposes of food production.

The factory was administered, under the Department, by a manager, Mr. Buckingham himself acting in this capacity during the early stages of experimental production.

Partly owing to the uncertainty as to whether the efficiency of the bullet would justify its production in bulk and partly to the urgency of the demand, all the early constructional work was of a temporary nature rapidly completed. On 21 July, 1917, the manager was instructed to proceed with the necessary constructional operations, and these advanced so rapidly that production was possible in September. The Air Board asked for supplies of R.T.S. bullets in August, 1917,

[1] Vol. XI, Part VI, Chap. VI ; HIST. REC./R/400/57 ; D.D.G.E./E.M.2/529, 1157, 1149.

and at the end of September, after some experimental work, the factory was instructed to proceed with the manufacture of 10,000 rounds. The first large output of 1,900 was delivered by 17 November, 1917, and in spite of a temporary delay due to a strike at Coventry, the 10,000 cartridges were completed in December, 1917. The Flying Corps reports on the quality of the ammunition being favourable, fresh construction was then begun to make the factory buildings more permanent and convenient. Production continued throughout 1918, rising from a weekly average of roughly 4,000 in January, to about 20,000 in March, while by June the estimated weekly delivery of 200,000 was made. This rate was usually maintained until the Armistice, after which production was maintained on a much smaller scale, 11 workers being employed in April, 1919, on a monthly output of 5,000 R.T.S. cartridges and on breaking down scrap bullets. On 6 September, 1919, manufacture ceased and a small amount of experimental work was transferred to the Enfield Small Arms Factory.

As the Coundon factory was only designed to meet the demand for R.T.S. ammunition which was comparatively small, it was planned on very limited lines. The estimated cost was between £5,000 and £7,000, and by March, 1918, when the factory was in full swing only 10 men and 66 women were employed. The capital expenditure to March, 1918, was £5,400, but additional expenditure was incurred during 1918 on constructional work, and by March, 1919, the total amount was £12,600.

IV. The Government Rolling Mills, Southampton.[1]

The establishment of the Government Rolling Mills for the production of brass and cupro-nickel strip followed as a result of the increased output of small arms ammunition sanctioned in the spring of 1916. For some time rejections of ·303-in. cartridges had occurred owing to the inferior quality of brass used, while the supply of cupro-nickel was falling short of the requirements even under the old small arms ammunition programme. When, therefore, the output of ammunition was raised in February, 1916, from 400,000,000 to 500,000,000 and later to 550,000,000 per month, increased supplies of metal were essential. By March, 1916, the scheme for a central government factory was sanctioned as being probably more effective than the alternative plan of extending existing plant in various factories. It was expected to economise labour, to avoid the difficulties due to the inferior and varying qualities of metal produced by small makers, to be able to make use of salvaged ammunition and finally to be a saleable commercial undertaking after the war.

Southampton was considered a suitable town in which to set up the mills, as it formed the delivery port for much of the raw material, possessed excellent transport facilities by land and water, and afforded a good labour field. With regard to the use of the mills after the war, a feature constantly kept in view during the design, the geographical

[1] Hist. Rec./H/1122.9/1 ; D.D.G.M. 057 ; Sec./Gen./709 ; M./Demob./68. For a further account of these mills, see Vol. XI, Part VI, Chap. VIII.

situation at Southampton was favourable for competition with the German export trade. The site selected was Weston Park, the property of the London and South-Western Railway Company, which lay at the junction of the River Itchen and Southampton Water. A branch line could easily connect the factory with the company's main line, which passed less than a mile away. 92 acres were taken over under the Defence of the Realm Act, and construction began in April, 1916.

An agreement was made at the end of March, 1916, with Mr. G. H. Robinson, a consulting engineer, thoroughly conversant with the German methods of casting and rolling. He undertook to superintend the lay-out, erection and equipment of the mills, and to manage them when ready for production. He was to receive £100 per month, and 1 per cent. on the cost of building and plant up to £5,000, and 5 per cent. on the first £100,000 saved by the factory over the usual market price of cups, with a minimum remuneration of £5,000 payable should hostilities end before construction was complete.

The factory was planned on an exceedingly large scale, to produce strip for 42,000,000 brass cups and an equal number of cupro-nickel cups per week, working day and night-shifts, a capacity four times as great as that of any other British mill. The cupping plant was included in the equipment, thus avoiding the transport and depreciation by dirt of the scrap which amounted to 40 per cent. of the total metal. The primary consideration in the lay-out of the factory was rapid and economical production, and the plant was designed to eliminate all unnecessary handling of materials and lessen the possibility of congestion. The factory had its own power-station and also gas-works, as special gas-fired melting furnaces, capable of greater heat than usual, were installed.

Production began at the end of February, 1917, and although for a time difficulty was experienced in the annealing plant, by the end of March about 5,000,000 Mark III Russian cups were being sent each week to the Government Cartridge Factories. In April, the output of fuse-stampings was delayed owing to the failure to secure deliveries of the lead required, and the managers made use of all the construction lead on the site. By the summer, the mills were working smoothly, and in November, 1917, the output of brass cups exceeded the estimated capacity on a day-shift, while the strip was considered to be of the highest quality. In 1918, production continued steadily in proportion to the requirements of the cartridge factories.

Of the labour employed in the Rolling Mills in October, 1918 (2,109), 753, or 35·7 per cent., were women. The greater number of these were discharged within a few weeks of the Armistice, as the manufacture of strip was stopped at once. Pending the decision of the Ministry as to the ultimate disposal of the factory, part of the plant was used for smelting non-ferrous scrap.

The estimated cost of buildings and machinery was £673,956, but by March, 1918, the capital expenditure was £1,089,900. Including the cost of land, the total expenditure on the factory to the end of 1918, amounted to some £1,200,000. The cost of production ranged from about £14 to £16 per ton, as compared with the trade price of £15 to £17.

CHAPTER VII.

NATIONAL ORDNANCE FACTORIES.

I. Introduction.[1]

Gun manufacture was undertaken at four National Ordnance Factories, three of which were originally used for other purposes, and turned over to gun work in 1917. The factories ultimately classed as National Ordnance Factories, and administered by the Gun Manufacture Department, were as follows :—

Name of Factory.	Purpose and Administration.	References in other Chapters.
Leeds	Taken over for shell manufacture by the Leeds Board of Management and managed by them. Classed as a National Projectile Factory, 1915–1917 ; National Ordnance Factory, 1917–1918.	p. 105
Nottingham ..	Erected by Messrs. Cammell Laird for shell manufacture and managed by them as a National Projectile Factory, 1915–1917 ; and as a National Ordnance Factory, 1917–1918.	p. 142
Sheffield	Erected by Messrs. Hadfield for shell manufacture and managed by them as a National Projectile Factory, 1915–1917 ; as a National Ordnance Factory, 1917–1918.	p. 146
New Basford ..	Taken over in 1917 for gun manufacture and managed by Coventry Ordnance Works as a National Ordnance Factory.	

A brief account of the Basford factory is given below, but the detailed history of the factories which originally made shell is related elsewhere. Another shell factory occasionally called a National Ordnance Factory since it made and repaired guns, was that at Ponders End, which came under the control of the Gun Ammunition Department, as a National Projectile Factory, in the last week of the war.[2] A factory engaged only on repair, the National Gun Carriage Repair Factory at Southampton, was administered by the Gun Manufacture Department, but its history belongs elsewhere.[3]

In the spring of 1917, the problem of gun repair was particularly urgent ; guns in the field were wearing out faster than they could be replaced ; and more ammunition was being produced than could be fired. It was, therefore, decided to convert some of the shell capacity

[1] Vol. X, Part I ; Hist. Rec./R/1122/20 ; C.G.M. 387/2, 3 ; C.G.M. 387Q ; (Printed) *Weekly Report*, 1918, *passim*

[2] *See* above p. 125. [3] *See* below p. 217.

at National Projectile Factories to gun repair, and among the factories where part of the plant was turned over were Messrs. Cammell Laird's factory at Nottingham, Messrs Hadfield's factory at Sheffield, and the Hunslet Shell Factory at Leeds. Nottingham and Leeds undertook 18-pdr. guns, and Sheffield 60-pdrs. All three began by re-lining guns, in addition to their shell work, but in a few months' time they were asked to undertake manufacture also, and by the end of the year all three had definitely turned from shell to gun work, and were thenceforward classed as National Ordnance Factories, their local administration remaining the same as before. The Hunslet factory at Leeds formed one of a group of factories managed by the Leeds Board of Management, but classed as National Projectile Factories for headquarters purposes, and when Hunslet ceased shell work the whole group was administered as National Ordnance Factories, though only one factory besides Hunslet did any gun work.

With the exception of Basford, little construction or alteration of buildings was necessary in connection with the National Ordnance Factories. At Leeds, a carriage erection shop was under construction in 1918, but was not completed at the time of the Armistice, the delay being largely due to lack of structural materials.

The Sheffield factory continued the repair and manufacture of 60-pdrs. until the end of the war, the only other gun work undertaken being the rifling of 8-in. howitzers. Leeds was mainly engaged on 18-pdrs., though 60-pdr. guns, 6-in., 8-in. and 9·2-in. howitzers were rifled and recuperator liners for 6-in. and 8-in. howitzers were manufactured there. Nottingham began with 18-pdrs., but early in 1918 the plant was converted for the new type of 6-in. gun. This factory was particularly well laid out, and its output was most valuable.

While repair work only was undertaken, some difficulty was experienced owing to the inconstant supply of guns for repair, but when manufacture began the factories were able to work the two programmes together and thus keep their capacity occupied.

A trouble from which all the factories suffered, more or less, was lack of skilled labour. At Nottingham, in August and September, 1918, the shortage of planers and turners was reported to be seriously holding up manufacture, and a similar lack of skilled men at Basford delayed development throughout the summer of 1918. At Leeds, in March, 1918, a strike occurred, owing to the alleged wrongful dismissal of four men, and all the factories were idle for some days. Some trouble was also experienced at Leeds with regard to dilution. Owing to the heavy nature of gun work, female labour could not be employed on a large scale. The only one of the factories which employed no women was Sheffield. The highest proportion of female labour was at Nottingham (1,366 out of 2,758 in April, 1918). At the time of the Armistice, out of approximately 5,700 employees at Nottingham, Sheffield, Leeds[1] and Basford, 22·8 per cent. were women.

[1] The figure for Leeds (1750; women 22·7 per cent.) is for Hunslet only. At the other factories, Newlay, Armley Road, and the fuse factories, there were 5,580 employees, 62·9 per cent. being women.

II. New Basford National Ordnance Factory.[1]

Towards the end of 1917 it was decided that a new type of automatic gun—the 37-mm. (1½-pdr.)—which had been developed by the Coventry Ordnance Works, should be provided in large numbers for the Air Force. The extensions necessary for manufacture on a large scale could not be undertaken at Coventry, and in December, 1917, a factory at New Basford, on the outskirts of Nottingham, was taken over under the Defence of the Realm Act. The factory, which occupied a floor space of about 40,000 square feet, was in use when taken over for the storage of machinery, and for lace manufacture. It was strongly built, but was old, rather dark, and badly ventilated, and considerable alterations were required. It was also some distance from a railway siding, though conveniently situated for the transit of workpeople. The factory was managed by the Coventry Ordnance Works as from 14 February, 1918, but the management agreement was not signed until June, 1919. The maximum output contemplated was 20 guns a week. Raw material was provided by the Ministry, who were responsible for all working costs. The firm received no management fee, but it was arranged that they should be paid royalties at the rate of £20 per gun for the first 500 guns manufactured (at Basford or elsewhere) and £10 per gun thereafter. Royalties amounting to £5,000 were also paid to the original designer of the gun.

The work of dismantling the old factory began at the end of 1917, and the installation of new plant started in February, 1918. Delays occurred in the delivery of machinery, but manufacture began in May. The first two guns were not completed till the second week of October, so that the factory had hardly got under way when the Armistice was signed, and the maximum output was never attained. Manufacture continued for a few months longer, but work ceased on 31 March, 1919.

The chief difficulty experienced at Basford was shortage of skilled labour, and the development period was prolonged owing to the lack of the skilled workmen required to supervise and train unskilled labour.

Wages were at first paid at plain time rates, but after a few months a special bonus for all operatives, amounting to about one-third of the standard time rate, was introduced, and this was continued until the the factory closed down. At the end of 1918 about 400 workpeople were employed, of whom 160 were women, the proportion of skilled labour to semi-skilled or unskilled in the machine shops being 1 to 3.

In October, 1918, after lengthy negotiations with the owner, arrangements were made to purchase the freehold for £14,500. Sums amounting to £3,500 were awarded to tenants for disturbance, and in December the capital expenditure on the factory was estimated at £46,500 for buildings and alterations, and £107,000 for machinery. The actual capital expenditure to 31 March, 1919, was £199,000.

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[1] C.G.M. 387Q; C.G.2/97; M.I.D./R/2774; Hist. Rec./R/1122/20; (Printed) *Weekly Report*, 1918, *passim*.

CHAPTER VIII.

NATIONAL FACTORIES FOR AIRCRAFT PRODUCTION.[1]

I. Introduction.

(a) *The Establishment of the Factories.*[2]

The sudden expansion of the aircraft programme in the summer of 1917 necessitated special steps for the production of aeronautical stores of all kinds. It was decided to reverse the policy of distributing the work among a large number of small producers and to concentrate in large units, for it was found that the tuition work involved in training the smaller firms was overtaking the supply of inspectors who undertook such duties as well as the actual testing of aircraft *matériel.* Moreover, questions of works organisation, assemblage space, finance and the allocation of material pointed to the superiority of the large unit, while experience in other branches of the Ministry tended in the same direction. The manufacture of the large bombing machines also necessitated large shops for assembly.

It was, therefore, decided to construct and equip several large aeroplane works at Government expense, to be operated under the control of the Department of Aircraft Production. Sanction was obtained in September, 1917, for the expenditure of £1,500,000 on three new factories for the production of aeroplanes, each with a capacity of 200 medium sized machines per month. Sites were selected at Croydon, Liverpool and Richmond, and arrangements were made for the management of the three new factories by Messrs. Holland, Hannen and Cubitt, Messrs. Cunard and Messrs. Sopwith respectively, on lines similar to those of the National Projectile Factories. The factory at Richmond was in reality a big assembly shop to be run by Messrs. Sopwith in conjunction with their other shops, and in the summer of 1918 it was decided that this should not be operated as a national factory, but should be rented from the Ministry by the Sopwith Aviation Company. A new factory at Heaton Chapel, belonging to Messrs. Crossley, the erection of which had been begun in the autumn of 1917, was selected for the third National Aeroplane Factory.

The limiting factor in engine production was the supply of skilled labour. Reorganisation of existing facilities appeared in 1917 to be the only way to increase production. In October, 1917, an aero-engine factory at Hayes, established at Government expense in the previous

[1] For the general policy of the Ministry in regard to the State manufacture of aircraft, *see* Vol. XII, Part I.

[2] A.S.0924/1918; A.S.914/3/1918; A.S.924/2/1918; A.S.02842/1918.

January, was taken over as a National Aero-engine Factory under Government control, since its output was not satisfactory, and the automobile works of Messrs. Clement Talbot, Ltd., at Ladbroke Grove were acquired on 1 January, 1918, for the repair of Rolls Royce aero-engines. The works of the Motor Radiator Manufacturing Company, at Greet and Sudbury, were taken over in January, 1918, under the Defence of the Realm Act. The requirement of balloons also increased very rapidly at the end of 1917, and the premises of Bohemia Ltd., a cinema firm at Finchley were acquired for a National Balloon Factory. The original programme for national factories included several other establishments, but they afterwards lapsed into the status of extensions of existing private contractors' works.[1] Factories which were established at Oldham for assembling American machines were under the control of the Alliance Aeroplane Company until December, 1918, when they were nationalised with a view to reorganising the methods of management.

Special arrangements were also necessary for increasing supplies of British ash timber, and kiln drying facilities were found to be a limiting factor. Private kilns had been established in various parts of the country, and to supplement this capacity two drying kilns were built at Swindon and Lancing to be run as national concerns.

In the case of Liverpool, Croydon and Heaton Chapel, sites had to be found and new premises erected at a time when all classes of building labour and material were difficult to obtain. The difficulties met with in regard to building materials and labour accounted to a large extent for delays which were experienced in getting these factories into operation. Certain alterations and extensions were needed at Finchley and Greet, but at Hayes and Sudbury no construction work was necessary. The output at Hayes, Greet and Sudbury after they became national factories, increased in a most satisfactory manner.

(*b*) *Methods of Administration.*[2]

A special Factories Branch under the Supply Department of Aircraft Production was instituted in March, 1918; but it was decided in July, 1918, to divide the headquarters control and vest the responsibility for allocating work to the national factories and for the supply of materials, both to the trade and national factories, in the Controller of the Supply Department, while the administrative duties connected with output, efficiency, finance, labour, etc., in the National Aircraft Factories were placed under the control of a new department, to be known as the National Aircraft Factories Department. The Controller of the Supply Department dealt with each National Factory practically in the same way as with an ordinary contractor by means of production officers, but referred in all matters of management to

[1] These were the works of the Birmingham Carriage Company at Smethwick, the Metropolitan Carriage Company at Birmingham, and Messrs. Clayton and Shuttleworth at Lincoln.

[2] N.A.F./41/11/2, 11/7/2, 11/5/1, 15/6/1.

the Controller of National Aircraft Factories, who was responsible for the management of the factories, and was the official channel of communication with the Ministry regarding all matters other than those specially delegated to the Supply, Inspection and Technical Departments. The Controller had direct authority to sanction capital expenditure not exceeding £1,000 in any one case. Schemes involving larger expenditure were submitted to the Munitions Works Board.

The form of agreement with the managers of the National Aircraft Factories varied. The agency agreements at Croydon, Liverpool and Heaton Chapel followed, however, the same general lines. The managers were to superintend the equipment and completion of the factory as soon as possible, to begin the manufacture of aeroplanes and parts as soon as sufficient plant was erected, and to run the factory for continuous production. They were to engage and maintain an adequate staff, employing women wherever possible, and to manufacture from material supplied by the Ministry, with permission to purchase their own material up to £200 in cases of extreme urgency only. They were to receive in remuneration every six months 1 per cent. of the value of plant installed during the first year, 1 per cent. of the value of the total output of the preceding six months, with a minimum sum payable of £5,000, and 1½ per cent. of the value of the interrupter gears produced in the same time calculated at £20 per gear. If the payment made to the managers caused such addition to the profits of their own business that they became liable to pay Excess Profits Duty, the Ministry undertook to pay the duty on the first £15,000 received by them in respect of aeroplanes and spare parts, and on the first £3,000 in respect of interrupter gears. The agreement might be terminated by either side on two months' notice. The fact that these agreements were not completed until several months after work was actually begun led to some confusion as to management in the early days.

The timber-drying kilns were managed by railway companies in whose works the kilns were erected, and the factories at Hayes and Finchley were managed by the Department of Aircraft Production directly. At Greet and Sudbury the existing management remained in control, and at Messrs. Clement Talbot's works the arrangements were peculiar, in that Messrs. Rolls Royce directed the works from a technical point of view. At each of the national factories the Ministry of Munitions was represented by a chief accountant. At first they were responsible to the factory managements, and in some cases, where they were formerly in the employment of the managing firms, their remuneration as factory officials was supplemented out of the funds of these firms. Under the Controller of National Aircraft Factories the position of the chief accountants was modified, and they became directly responsible to the Controller, their salaries being paid direct from headquarters.

The need for an increased output of aeroplanes was so urgent at the end of 1917 that special schemes were devised with the purpose of hastening the construction of the new aeroplane factories. The principal stipulation made was that a factory of stated capacity should

be erected and equipped within a stated time. The managing firms were to superintend the construction and equipment, and were paid part of their remuneration by a percentage on the cost of new buildings and plant. No detailed specification of the buildings were in existence when the expenditure was sanctioned, but the need for increased output made it difficult to wait for more economical methods. About 97 per cent. of the expenditure on factory construction had been incurred when the National Aircraft Factories Department came into existence, but from that time no new expenditure was sanctioned until detailed estimates were submitted and the fullest investigation made as to the necessity for the work.

The total cost of the State factories for aircraft production had amounted to £2,462,800 by the end of March, 1919. Of this sum by far the largest proportion, viz. £2,015,700, was the cost of the three factories for manufacturing complete machines at Aintree, Heaton Chapel and Croydon.

(c) *Accounts and Costing Systems.*[1]

Instructions as to the supply of materials to National Aircraft Factories were issued by the Supply Department in March, 1918. It was then laid down that except in special or urgent cases sanction should be obtained from the Ministry for all orders for material exceeding £200 in value. This regulation was by no means strictly kept, and some of the factories placed direct purchase orders for large amounts without reference to headquarters and accumulated stocks to an unjustifiable extent. The necessity for a more detailed system of control became apparent and such a system was instituted in October, 1918. By this the Ministry was protected against the risk of financial loss due to over-ordering, or irregular payments, and against the inequitable distribution of material and competition between buyers for various factories or the placing of large orders by the managing firms with their own shops. Delay in supply was not infrequent, and was often unavoidable owing to shortage of certain kinds of material. On the other hand, the factory managements did not always appreciate the necessity of anticipating their requirements.

In the agreements made with the various managers of the national factories it was laid down that efficient costing systems were to be set up. The method was, however, left to the discretion of the managers. The manager of Hayes Factory reported in January, 1918, that, owing to the unsatisfactory conditions obtaining at the factory in the past, it had been impossible to obtain even approximate figures of costs, but he hoped under a system which he had instituted to be able to give accurate results in the future. He suggested that a definite system should be laid down for all the national factories, but it was not until October, 1918, that a detailed system of costing was instituted for the purpose of determining the actual cost of manufacturing each unit, component and part. The difficulty of obtaining prices for stores in and out of the factories made cost accounts very difficult, and at

[1] N.A.F./41/11/2, 31/7/1, 11/8/2; A.S.17290/1918, 37532/1918, 14440/1918.

Aintree the confused state of stores accounts made it impossible to obtain costs. The expense of the system was considered to be no longer justified after the Armistice, and it was discontinued. When the system was inaugurated in October, the question was raised as to whether factory costs could be fairly compared with manufacturers' costs. The amount of depreciation to be written off the various assets was fixed by the Director of Factory Audits and Costs, and the rates were high compared with commercial standards, so that the overhead charges of the factory were unduly inflated. Comparison was also hampered by diversity of circumstances, as, for instance, at Hayes, where the relative smallness of the amount of work allocated made it impossible to work on economic lines, as it was necessary to cover the initial cost of jigs and tools on the price of a very small number of parts. In the case of balloon manufacture it was impossible to obtain costs for each operation, and for the purpose of costing, the manufacture was divided into three or four sections, each representing several operations. For the purpose of aeroplane costing the operations were divided as follows: (1) assembly of complete aeroplanes, (2) assembly of units, *e.g.* main planes, fusilage, (3) assembly of components forming each unit, (4) manufacture of parts required for each component.

The accounting work in connection with the National Aircraft Factories up to 30 September, 1918, was of exceptional difficulty, mainly owing to the non-observance of Ministry procedure by the factory managers and superintendents, and to difficulty experienced in obtaining the prices of stores, materials, machinery, etc., supplied through other departments of the Ministry. The managing firms who controlled agency factories were at first almost entirely unacquainted with rules and regulations governing expenditure on behalf of a Department of State.

The records, both of capital expenditure and of production payments, were very incomplete owing to the number of Headquarters Departments involved. In many cases where the prices of goods supplied had not been fixed at the end of 1918, these unpriced materials were regarded for accounting purposes as free issues, so that it became impossible to show the actual production expenditure, or the cost of the aircraft produced at the national factories.

(*d*) *Labour in National Aircraft Factories.*

Labour unrest was a constant source of difficulty in connection with the administration of the National Aircraft Factories. This applies particularly to Croydon and Aintree, and in a minor degree to Heaton Chapel and Kensington (Clement Talbot). On the other hand, labour disputes were of rare occurrence at Hayes, Greet and Sudbury, partly, probably, because the Ministry took over the employees of the former owners of these factories. The unsatisfactory nature of the output from the new National Aeroplane Factories was largely attributable to the labour conditions obtaining in these factories.

A production bonus was in operation for the workpeople at Heaton Chapel and Aintree. At Croydon one was sanctioned on 4 October, 1918, for the interrupter gear operatives, and at the Armistice one was

about to be authorized for the aeroplane workers. At Hayes, piece-work was impracticable owing to the varied nature of the work, which consisted in the production of aero engine spares of numerous types, and in experimental work. The introduction of the ordinary production bonus was in contemplation at the time of the Armistice,[1] but some consideration in the form of a bonus on the value of the output was paid for some time before. It was also intended to allow a production bonus at the works of Clement Talbot, into which the shop bonus previously in operation was to have been merged, but this was abandoned at the Armistice. With the consent of the Labour Supply Department, the foremen were allowed an output bonus, with good effect upon production.

In the autumn of 1918, the employees in the National Aircraft Factories, exclusive of the Timber Drying Kilns, numbered 12,500, of whom 38·4 per cent. were women.

II. Individual Aircraft Factories.

The Aintree National Aircraft Factory, Liverpool (N.A.F.3).[2]

When plans were made in the summer of 1917, for the increased production of aeroplanes, the Cunard Steamship Company undertook to manage a factory at Aintree, Liverpool. The proposal was laid before the company in September, 1917, and an agreement was finally drawn up similar to that signed by Messrs. Cubitt, for the Croydon factory,[3] but at Liverpool, provision was made only for the manufacture of aeroplanes and spare parts, and not for interrupter gears. An annual payment of £1,000 was made to the firm in respect of supervision and was deducted from the 1 per cent. commission on output. The agreement with the firm was determined in September, 1918, on account of the small output reached, and the factory was directly controlled by the Ministry from the following November.

Rather more than 70 acres of land was acquired, under the Defence of the Realm Act, next to the Aintree race-course, which was used as a flying ground. Construction was begun on 4 October, 1917, but progress fell considerably behind expectations owing to the difficulties which arose in providing an adequate water supply and in laying connections with the Lancashire and Yorkshire Railway, while constructional work generally was much impeded by severe weather. Delay was also occasioned by the lack of a suitable type of labour. There appeared to be little difficulty in finding sufficient numbers, mostly Irish, but it was of very poor value. Early in 1918, over 3,000 labourers were employed on construction, but were reported to be "deplorable in spirit and quality," and ready to cease work for most trivial reasons. In March, many of the Irishmen left the country owing to the new Registration Act, and a labour officer was appointed

[1] N.A.F. 82/17/6.
[2] A.S. 913/1918; A.S. 0924/1918; M.C. 238; A.S. 0833/1918; N.A.F. 41/11/2.
[3] *See* above p. 199.

to deal with all questions of male labour. It was considered, later, that the large degree of autonomy accorded to the management had led to extravagance in the equipment of this factory, and that at Heaton Chapel. Building was complete in mid-July, 1917; but the layout was disappointing as it did not tend to efficient work or easy supervision.[1]

Although the office staff was established in March, 1918, production could not begin for several weeks, while the first finished machine was not despatched until 15 June, 1918. The managers undertook to construct 40 aeroplanes of the "Bristol Fighter" type per week, but the rate of production was at first extremely disappointing, 36 machines only having been delivered before 1 October, 1918, and, of those, 12 without engines. Manufacture, however, continued after the Armistice, and the total output of machines by the end of March, 1919, was 126.

Dilution was carried out to a considerable extent, and in September, 1918, of 2,634 employees, 1,054 (40·5 per cent.) were women. Labour difficulties, at first a serious problem, became acute in November, 1918, after the reorganisation of the management.

The capital expenditure to March, 1919, was £692,900.

Heaton Chapel National Aircraft Factory, Manchester (N.A.F.2).[2]

The National Aircraft Factory at Manchester was initiated as a trade factory in the autumn of 1917, in accordance with the scheme for the increased production of aircraft evolved during the summer. Sanction was given to the project in September of that year. The management was subsequently undertaken by Crossley Motors, Ltd., along the lines of the agreement common to the three National Aircraft Factories,[3] with certain modifications. It was agreed that should production be achieved under schedule prices, the firm should receive 15 per cent. on the reduction of costs effected. Messrs. Crossley superintended the erection of the factory, for which a separate building contract was made with Messrs. Matthews & Sons, and were responsible for the cost, receiving a commission of 1 per cent. on the sums payable to the builders during the first year. A standing contract with the firm for 500 machines was superseded by the new agreement, and a guarantee was given that the full output of 40 machines weekly should be reached by 1 July, 1918. In June, 1918, a separate agreement was drawn up by which the Government was to purchase the fee simple of the land from the firm for £15,000, and to reimburse to Messrs. Crossley the cost of construction, amounting to approximately £400,000. The firm was also granted the option of purchasing the factory within 12 months of the cessation of hostilities at 45 per cent. of the original cost.

The site selected was about 22 acres in extent, and ample space for a flying ground was attached to the factory. Construction began on 9 October, 1917, but was delayed by the need for extensive excavation.

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[1] Aircraft Supply Committee, Report on National Factories, 13.7.18.

[2] A.S.913/1918, 0924/1918; HIST. REC./H/1960/2; A.S 923/1918; N.A.F. 10/5/1, 31/7/1;

[3] *See* above p. 199.

Many difficulties arose during the course of erection, and the two aircraft factories being erected directly by the Ministry were granted a higher priority in obtaining labour and supplies than the Heaton Chapel factory which this firm was erecting. In spite of the many efforts made by Messrs. Matthews, the builders, to overcome this difficulty, all kinds of supplies were constantly delayed. In December, 1917, the firm was granted first-class priority for most of the material required and better progress was made. In July, 1918, extensions were arranged for the manufacture of Dragonfly engines.

Messrs. Crossley undertook the construction of D.H. 9 and D.H. 10 aeroplanes, but they were unable to reach the estimated output of 40 machines weekly. Manufacture began in April, and by the end of the summer the factory was making good progress. In October, machines were delayed owing to difficulty in obtaining engines, but the total output from Heaton Chapel before 31 March, 1919, was 326 aeroplanes, a figure considerably in excess of that shown by either of the other two National Aircraft Factories.

The labour difficulties were similar to those at Liverpool, although the numbers employed were not quite so great. No difficulty was anticipated in obtaining female labour, but dilution was not carried out quite so extensively as in other factories. Out of 2,540 employees in September, 1918, only 940 (37·5 per cent.) were women.

The approximate production expenditure to the end of March, 1919, amounted to £1,198,512, but the comparatively high output at Heaton Chapel was obtained from plant and buildings erected at a relatively low cost, the capital expenditure to March, 1919, being little more than £544,500.

Waddon National Aircraft Factory, Croydon (*N.A.F.1*).[1]

After the consideration and rejection of a site at Watford, Messrs. Holland, Hannen & Cubitt undertook, towards the end of September, 1917, to manage a factory at Waddon, near Croydon, and the proposed site was taken over under the Defence of the Realm Regulations. It consisted of about 198 acres of flat land at a fairly high level, which gave an ample flying ground and had reasonable travelling facilities, there being three stations within a distance of one mile. Construction began during the last week of September, and a member of the managing firm visited the Handley Page aircraft factory to investigate methods of production. Work was pushed on with all speed, and night-shifts were at work in November, but early in the new year progress was much impeded by a shortage of steelwork and by very bad weather, while the general inexperience of all concerned as to aircraft production caused the rate, both of construction and later of production, to fall short of the programme. By 18 January, 1918, the office staff was installed, and by the middle of March part of the factory was sufficiently equipped for manufacture to begin. All building work was practically finished by 13 July, 1918.

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[1] A.S. 913/1918, 0924/1918, 0789/1918, 23276/1917; 37715/1917; N.A.F. 24/4/3, 4; Hist. Rec./H/1960/2.

The factory was laid out to produce 40 D.H. 9 machines plus spare parts, and 600 C.C. interrupter gears weekly. The first complete machine was delivered by the first week of April, and the total production by 31 March, 1919, was 241 aeroplanes and 3,000[1] C.C. gears. The factory never reached its estimated rate of production. The average output weekly, from August to October, 1918, was eight or nine machines only. In September, the output of C.C. gears was 50 per week. The unsatisfactory output was attributed largely to labour conditions among the electrical and woodworking trades and also to unsatisfactory management.

Labour conditions were particularly difficult at Waddon, where perpetual unrest was felt and the position was never satisfactory. About 2,000 labourers were employed on construction during the winter. In April, 1918, after manufacture started, 1,900 workers were employed, of whom about 50 per cent. were women, but it was estimated that in May, when the factory was complete, the number would have to be raised to from 5,000, to 7,000, 35 per cent. of whom would be on night shift. It was originally intended that 70 per cent. of the staff should be women; but at the beginning of November there were 200 women and 168 men on the staff and 1,791 men and 1,438 women working on the machines, so that of the total number (3,597) only 45·5 per cent. were women. Perpetual disputes occurred between the labourers and management; in May a strike of electricians resulted in some wilful damage to the electric supply plant, and in August the estimated output could have been reached but for labour disputes on the subject of wages, which were holding up the output of C.C. gears.

Nearly all the expenditure (97 per cent.) was incurred before the establishment of the National Aircraft Factories Department, which instituted a rather closer control over finance than had formerly existed. Considerable difficulty was experienced in estimating the exact expenditure involved in establishing the factory, since in order to hasten erection and begin work construction was begun on the "time and line" basis before detailed drawings and specifications were available. In August, 1917, when the site at Watford was considered, the estimated capital expenditure was roughly £290,350. The actual capital expenditure to March, 1919, was £778,300.

III. Individual Aero-Engine Factories.

National Aero-Engine Factory, Ladbroke Grove (Messrs. Clement Talbot, Ltd.).[2]

Very heavy demands for Rolls Royce engines were received by the Controller of Aeronautical Supplies in August, 1917, and special steps became necessary to hasten their production. The works of Messrs.

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[1] *See* HIST. REC./H/1960/2. Part I, Chap. XIX. Appendix.

[2] A.S. 8523/1917, 23290/1917, 36441/1917, 2403/1918, 12316/1918, 17841/1918; N.A.F. 93/15/7, 94/4/1; HIST. REC./H/1960/2; Minutes and Reports of Aircraft Supply Committee.

Clement Talbot at Ladbroke Grove were selected by the department as suitable for the purpose of repairing and producing spares for Rolls Royce engines. The firm was at that time chiefly employed on mechanical transport work, but they had suitable premises and plant for aero-engine work and had done some repairs to French aero-engines for naval service. Considerable delay occurred in starting on repair work. The provision of drawings from Messrs. Rolls Royce took three months, and as that firm was unable to provide jigs and tools, further delay occurred while Messrs. Clement Talbot manufactured those necessary. Great difficulty was experienced in cancelling the car contracts until the whole of the shops could be occupied in the manufacture of aero-engine parts.

Moreover, the change was scarcely to the interest of the managing firm, who had for many years been established makers of motor-cars and were suddenly called upon to undertake for a rival firm repairs of an aero-engine, with which they were unfamiliar. They feared that the scheme would involve them in post-war losses of money and prestige, and were accordingly unfavourably disposed towards it.

By the end of December little progress had been made, and since the requirements of the service for Rolls Royce engines were greatly increased at this time, some immediate steps became necessary. A conference was held between representatives of the Department, Messrs. Clement Talbot and Messrs. Rolls Royce, and it was agreed that the mechanical transport work should be cleared as soon as possible, and that the only work of this sort to be done by the firm in the future should be spares for the Talbot cars and ambulances, then running for the British Army, the rest of the capacity of the shop being turned over to the repair and manufacture of spare parts for Rolls Royce aero-engines. Messrs. Rolls Royce were to be responsible for the output and technical correctness of the work done in the Clement Talbot shops, sending technical experts to instruct the works manager there, but the latter was responsible for the general control of the works. All orders for repairs were given to Messrs. Rolls Royce, who allocated to Messrs. Clement Talbot as they thought fit, and were responsible for the proper supply of raw material. Messrs. Rolls Royce received a management fee for supervision.

The works were taken over by the Ministry on 1 January, 1918, at an annual rental and £202,996 was paid for the stock in trade. The agreement which took effect from 1 January, 1918, was to continue six months after the war, unless previously determined upon three months notice. At the termination of the agreement the company agreed to purchase all stock and work in progress. During the currency of the agreement the Minister paid to the company besides the annual rent and an annual sum for depreciation, a bonus of £5 per engine in respect of all engines repaired per week in excess of 15 up to 30 and £10 per engine in respect of all engines repaired per week in excess of 30. Arrangements were also made for the payment of a bonus on economical working according to a scheme to be prepared at the end of 1918 and to be applied retrospectively. The Ministry also paid all labour costs and overhead charges, excluding Directors' fees and salaries of the

managing staff, which were deemed to be covered by the amount of the rent and other remuneration.

Friction between Messrs. Rolls Royce's representatives and Messrs. Clement Talbot's managing staff still continued during 1918, and there was also much dissatisfaction among the foremen, because they understood that Rolls Royce employees were receiving higher rates of pay.[1] The question was raised in July as to whether these works should be taken from under the control of the Rolls Royce scheme, and in May a modification had been made as to the allocation of engines for repair between the two firms. From May the service section dealing with engines undertook direct allocation, on a basis of 60 per cent. to Messrs. Rolls Royce and 40 per cent. to Messrs. Clement Talbot, engines from the districts nearest Derby being sent to the former, and from the district near London to the latter. In August some changes were made in the managing staff at Messrs. Clement Talbot and a nominee of the Department of Aircraft Production was appointed as superintendent. Considerable improvement followed this reorganisation, and the agreement held good until the Armistice. The premises reverted to Messrs. Clement Talbot on 28 February, 1919. The total output of repaired aero-engines during the period while the works were run as a national factory was 608, the value being approximately £723,520, and it was hoped in October, 1918, that the output would eventually rise to 240 engines per month. Of a total of 1994 employees on 11 November, 1918, 371 (18·6 per cent.) were women. The capital expenditure to March, 1919, was £141,700.

National Aero-Engine Factory, Hayes.[2]

Arrangements were made in January, 1917, between the War Department and Messrs. Mitchell, Shaw and Co., Ltd., under which Mr. Mitchell should purchase the Goss Printing Works, at Hayes, Middlesex, over which he had secured an option of purchase at £95,000, in order to undertake a large contract for the supply of aero-engine parts then urgently required. Messrs. Mitchell, Shaw and Company as the Staines Projectile Factory, had been reported as having done very satisfactory work for the Ministry of Munitions. The War Department authorized the purchase of property and the provision of plant within a total sum of £135,000 out of money provided by the Government. The firm were to act as managers, receiving no working salary, but taking over the factory at the end of the war at a nominal sum of £100 if they succeeded in producing at half the ruling prices, which on the estimated output would save large sums to the Government. Mr. Mitchell accordingly entered into an agreement with the Goss Company on 26 January, 1917, to purchase the works for £95,000 plus £3,250 for work in progress. In February he entered into a contract for extensions amounting to £5,700.

[1] Aircraft Supply Committee: Report on National Factories, 13.7.18.
[2] A.S. 4806/1918, 9597/1918, 8746/1918; N.A.F. 82/17/15, 83/15/3, 84/4/1; HIST. REC./R/400/12.

The Ministry of Munitions decided in October, 1917, to take over the management of the factory, as the output was not satisfactory. Mr. Mitchell acknowledged that the factory and plant were the absolute property of the Government and cancelled the arrangement under which the property should become his for a nominal sum.

After the change in management the organisation of the factory was much improved, and production increased. The factory eventually reached a particularly high standard in quality and quantity of output, efficiency of control and administration and freedom from labour difficulties. The wages obtaining there were in excess of the London district rates, and this caused some dissatisfaction in neighbouring factories, but no attempt could be made to adjust this without changing the rates which had already been established when the works became a national factory in October, 1917. Skilled labour was very essential in this factory for in June, 1918, it had been organised specially to deal with urgent requirements. The consequent constant changes in employment prevented the production of the factory reaching as high a figure as would have been the case had it been employed on repetition work. The nature of the employment in this factory to some extent precluded dilution, but in August, 1918, the dilution percentage was 38 and the management were working with a view to increasing this to 60 per cent. by the employment of discharged soldiers and women. The number of employees in October, 1918, was 761, of whom 213 (28·5 per cent.) were women.

Some extensions were made after the factory was taken over by the Ministry, the total cost being about £193,000, of which about £48,000 was written off to production as depreciation. The explanation of this was that the factory was originally intended for the manufacture of printing machinery, and the option price of £95,000 covered plant, stock and goodwill for that purpose. The balance sheet of the factory as an aero-engine factory was opened with the value stated as £52,000. The total capital expenditure to 2 April, 1919, was £211,346. The value of the output, which can only be assessed in this form owing to the variety of the work, was £348,992 from January, 1917, to 31 March, 1919. The factory was sold in September, 1919, to the Cosmos Consolidated Company for £112,500.

IV. The National Balloon Factory, Finchley.[1]

In order to meet the large demands for kite balloons in connexion with the anti-submarine programme and home defence scheme at the end of 1917, it became necessary to establish a national balloon factory. It was decided to take over a picture palace at Finchley, the property of Bohemia, Ltd. On 21 January, 1918, the premises were taken over under the Defence of the Realm Act for £18,500. A sum of £8,105 was approved by the Munitions Works Board for plant and alterations, but subsequently this amount was increased

[1] N.A.F. 51/13/1, 51/11/3, 52/10/1; Hist. Rec./H/1960/2.

to about £16,000 of which about £11,000 was for building and the rest for structural alterations and furniture.

It was at first suggested that the Sidney Davidson Balloon Company should take over the new factory as an extension of their works, but finally it was agreed that this company and the Davidson Aviation Company should manage the factory on behalf of the Department, in co-partnership. Considerable delay occurred in completing the agreement for management, and it was decided in July, 1918, that the factory should be operated directly under the Controller of National Aircraft Factories, and the two companies were notified that their services were no longer required. Their joint remuneration for the period during which they acted as managers was agreed at the rate of £2,500 per annum.

The factory was used for the production of Caquot and Nurse balloons, and output began in April, 1918. The output of balloons varied greatly from week to week owing to intermittent supplies of material, but in October an output of ten a week was aimed at, and in the week ending 28 September nine had been produced. The total number of balloons produced up to 31 March, 1919, was 118, and the cost per balloon was reduced very considerably, as the following figures show :—

	£	Number Completed.
Approximate cost per balloon (R type) under old management to 2 July, 1918	400	12
Approximate cost, 2 July to 27 August	324	18
,, ,, 27 August to 30 September ..	275	10

A scheme for a bonus on production was being worked out at the time of the Armistice.

Difficulties in regard to labour conditions were increased during the summer of 1915, by pledges already given to the workers before the Controller took the factory over. In September labour difficulties were increased by the majority of the workers joining the Amalgamated Union of Engine and Crane Men, Boiler Firemen and Wire-rope Workers. The union immediately applied for increases of pay to the employees. The female workers had received a recent advance of 5s. a week which involved an increase of aproximately 5 per cent. on costing, and the further advance required, for which no reason was given, would have involved an additional 5 per cent. on costing. The women, whose wages compared very favourably with the district rate, had been quite content until they were disturbed by the active members of the union,[1] and the further increase demanded was not sanctioned. A large proportion of the employees were women, and at the date of the Armistice of a total of 297 employed 270 (90·9 per cent.) were women.

The factory was closed on 8 February, 1919, and was sold about June, 1919, to the Kiwi Polish Company. The capital expenditure up to the end of March, 1919, had been £16,500.

[1] N.A.F. 52/10/1 ; 52/17/4.

V. National Radiator Factories, Greet and Sudbury.[1]

The advent of large bombing machines in the summer of 1917, raised a serious problem in the supply of radiators. All the heavy bombers had water-cooled engines requiring radiators of special construction, and it was found in August, 1917, that the capacity for radiator production was only a quarter of the requirement. The conditions prevailing in the trade were peculiar, for the number of firms engaged in the manufacture of radiators was less than a dozen, and most of them were small scale businesses. The employees, whose work was at a premium from the beginning of the war, were in most cases members of the Sheet Metal Workers' Union, and from the outset they resisted dilution and opposed everything tending in the direction of quantity production, so that increased output under existing circumstances was impossible. The position was so serious that the Department of Aeronautical Supply was obliged to assume control of the supply of radiators, which had previously been obtained independently by the aeroplane manufacturers, from the radiator firms. Contracts were re-arranged in order to reduce the number of types manufactured by each firm, and the development of a radiator factory on the lines of a national factory was decided upon.

The factory of the Motor Radiator Manufacturing Company, Greet, near Birmingham, offered several advantages for this purpose. It was laid out for the production of tube honeycomb radiators on a fairly large scale and produced 40 to 50 radiators a week. The plant was entirely self-contained, having a tube-mill producing all the tube necessary for the output of radiators. The buildings were modern and well lighted, the site was good and there was ample land available for extensions. Moreover the management was efficient and progressive, and since the employees were not members of the Sheet Metal Workers Union, the factory had for years been free from labour troubles.

After ineffectual efforts to transfer the business, which belonged to a Norwegian, to an English firm, it was finally decided to take over the factory under the Defence of the Realm Act. This was done on 1 January, 1918, and an extension of plant and works to treble the output was arranged in March. The negotiations for the purchase of the factory were prolonged, and were not finally settled until August, when a sum of £30,000 was paid as part payment of interest in the concern, and for stock and work in progress on 31 December, 1917.

Meanwhile the factory was run as closely as possible on the lines of a national factory although the management kept accounts in the same way as a private company, and tendered as before against other concerns for radiator contracts. Before the factory was taken over certain members of the staff had been paid on a salary plus profits bonus basis, and the employees worked on a piecework and profit bonus system. In view of the freedom of this factory from labour troubles it

[1] N.A.F. 101/7/2; A.S. 28590/1918, 3120/1918, 23932/1918, 26986/1918, 72286/1918; Hist. Rec./H/1960/2.

seemed advisable to continue this arrangement as far as possible, but in a national factory a scheme based on profits was impossible. The scheme finally agreed to was based on the output of radiators, with various bonus units corresponding to the previous percentage profits units. Some questions were raised as to the high salaries being paid under this scheme to the managing staff, but it was contended that the peculiar conditions existing in the industry justified this, which was the only way to obtain the full benefit of the experience of the firm and the staff as a whole. Radiator production in June, 1918, was barely abreast of requirements, and there was no margin available, so that every strike of the Sheet Metal Workers Union held up the production of aeroplanes, and continuous output from Greet was of the first importance. The efficiency of the factory justified a high remuneration for the management, especially as in this case nothing was paid to a managing firm. In 9 months from October to June, 1918, the total output of radiators increased tenfold. The output of the factory when complete was estimated at about 600 radiators a week, and even before the extensions were completed 20 per cent. of the Air Board requirements were supplied from Greet. The following are figures of output.

	Number of Radiators.
January, 1918 (5 weeks)	255
February (4 weeks)	327
March (4 weeks)	478
April (4 weeks)	556
May (5 weeks)	627
June (4 weeks)	619

A great advantage was gained by allowing the factory to tender for contracts in competition with private firms, for the factory tenders, allowing for liberal profits, were 10 to 20 per cent. lower than others obtained from private concerns, and this was of great value in negotiating with firms and reducing the cost of radiator production. At Greet was the only plant in the Kingdom producing radiator tubes by the Draw Bench method, and it produced tube at 4s. 9d. per lb. for which contractors charged 11s. 6d.

The management recruited and trained its own employees and the following figures show the extent to which dilution was effected during the first five months of 1918.

1918.	Employees.			Wages percentage to output.
	Men.	Women.	Total.	
January	169	106	275	28
February	183	151	334	23·6
March	198	192	390	21·3
April	206	236	442	18·7
May	237	213	450	16·9

By the end of October the total numbers had risen to 624, of whom 285 (45·7 per cent.) were women.

The factory at Sudbury, Suffolk, was a branch of that at Greet and was taken over with it. Until April, 1918, no separate accounts were kept for the Sudbury branch, material was supplied from Greet, and work done at Sudbury was treated in the same manner as if it had been carried out at Greet. The manager was responsible to the manager at Greet. As from 1 May, 1918, a new system of accounting was adopted, and accounts were kept at Greet for recording the transactions of the Sudbury factory, so that at fixed intervals profits and loss accounts and balance sheets could be prepared. Otherwise the management at Sudbury remained unaltered. Difficulty in obtaining labour made the employment of the Sudbury factory up to its full capacity impossible. At one time under 30 people were employed, though there was capacity for 130 to 150, and at the end of October there were only 56, 29 of whom were women. In July, 1918, Sudbury was organised to deal with the salvage and repair of radiators received from the Expeditionary Force. Some small additions were required to facilitate this work. The factory kept account of the costs of repair and salvage and added 100 per cent. for overhead charges plus 10 per cent. for profit. Great economies were effected, and for the three months ending 30 September, 1918, the value of the recovered material was £10,000, against which the wages bill totalled £1,500.

The factories at Greet and Sudbury were of the greatest value for emergency work throughout 1918. As an example of this the following may be quoted. Early in February, 1918, when the S.E. 5, a new scout machine, was approaching completion, it was decided to equip it with an underslung radiator of new design. No difficulty was anticipated as this type of radiator had been successful in the D.H. 9 aeroplane and some 2,000 radiators were put into production; but the first air trials showed that the speed of the machine was seriously reduced when fitted with this radiator. A conference of the designer of the S.E. 5 with the works manager of the Radiator Factory resulted in the preparation of rough drawings of a new type of radiator, and by working continuously by these rough drawings a new and successful radiator was despatched to Farnborough for trial within 48 hours of its conception. In the following week 40 pairs of this radiator were delivered from the factory, the next week 60, the next week 80, and the following weeks 100, so that the anticipated stoppage in the production of machines was entirely avoided. In the last weeks of March, when the Germans made their great effort, over 100 S.E. 5 radiators were shot through, and in order to replace them a special staff of courier air mechanics was provided. As each new radiator was completed at Greet an air mechanic set off with it and personally delivered it to its required destination in France.

The total output from both factories from 1 January, 1918, to 31 March, 1919, was 6297 radiators.

The capital expenditure on the two factories (Greet and Sudbury) up to March, 1919, was £64,600.

VI. National Timber Drying Kilns, Swindon and Lancing.[1]

The demand for aeroplane timber in September, 1917, necessitated the provision of facilities for kiln-drying British ash timber. In the autumn of 1917 a large number of kilns were put up by private firms, and it was arranged that some should be erected at the works of various railways. The Great Western Railway Company was at that time considering the erection of a kiln at Swindon for the post-war requirements of the company. Swindon was a peculiarly suitable site for serving the needs of the south-western district, owing to its railway facilities and to the fact that the company had an adequate sawing plant there, and negotiations were commenced by the Ministry with a view to securing the use of this kiln during the war. The first proposal was that the Ministry should build the kiln, but, since it was to be taken over by the company after the war, they preferred to supervise the erection, and it was finally agreed that the company should build at cost plus 12½ per cent., and buy the whole at a fair valuation after the war.

The building of a second kiln at Lancing in the works of the London Brighton and South Coast Railway was carried out by the Ministry, the railway company agreeing to take over the buildings at a valuation after the war. In the case both of Lancing and Swindon the companies undertook to manage the works after completion, on the terms of the general Government agreement with railway companies, under which all war work was carried out at cost price plus 12½ per cent. for superintendence. In order to simplify finance, the headquarters administration of the kilns was placed under the Controller of National Aircraft Factories, instead of directly under the Controller of Supplies (Aircraft Production), as at first suggested. Both kilns were finished in June, 1918, and started work in July.

The estimated cost of erection was £4,400 in the case of Swindon and £3,500 in the case of Lancing, but both these estimates were exceeded. At Swindon improvements were incorporated during construction with a view to the post-war utility of the kiln, and at Lancing the extra cost was accounted for by the smallness of the contract and the poor quality of labour obtainable in the district. The final cost of the Swindon kiln was £6,510, and of Lancing £6,500: the capacity at Swindon, a four-compartment kiln, was 4,000 cubic feet per month, and the approximate total output to 31 March, 1919, 9,800 cubic feet. The capacity at Lancing, a two-compartment kiln, was 2,000 cubic feet per month and the approximate output to 31 March, 1919, 5,000 cubic feet. At this date both kilns were handed over to the railway companies. The surplus capital expenditure for the Swindon kiln was sanctioned by the Munitions Works Board in November, 1918, but the outlay on the kiln at Lancing had been made under the authority of the Railway Executive Committee, and sanction by the Board was not considered necessary.

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[1] A.S. 36172/1917, 27372/1917; N.A.F. 64/4/1.

CHAPTER IX.

MISCELLANEOUS NATIONAL FACTORIES.

I. National Gauge and Tool Factories.[1]

Certain classes of factory equipment, namely gauges, small tools and ball-bearings were manufactured to some extent in state factories. The National Gauge Factories were in practically every case existing trade establishments which by agreement between the Ministry and the proprietary firms were reorganised and placed under the administrative and financial control of the Ministry. These agreements arose from the necessity of increasing the supplies of gauges, combined with the difficulties involved in spreading small contracts over a large number of firms which were themselves in difficulties as to labour and precision machinery. The urgent need for immediate supply and the problem of finding the necessary staff prevented the erection of one central state gauge factory, as was at times suggested, and consequently various successful makers were selected to whom aid was given to extend their existing works on behalf of the Government.

The first factories so organised were at Woolwich, Birmingham and Croydon, where in the summer and autumn of 1915 engineering firms agreed to extend or adapt their works for gauge production and to manage them under the direction of the Ministry. The financial arrangements made with the different firms varied considerably and were subsequently revised at intervals, but in each case the Ministry eventually became responsible for all or the greater part of the cost of extension and absorbed the whole of the finished output.

In 1917, the Wolseley Motor Company at Pimlico and in the spring of 1918, the Newall Engineering Company at Walthamstow undertook gauge manufacture for the Government. In these two cases the Ministry took over the entire management of the factories, although, with the exception of new buildings and plant erected during the war, they remained the property of the firm, who received a fixed sum annually as profit and in respect of depreciation of machinery. The cost of working and maintaining the factories was borne by the Ministry. In May, 1917, the Fairfax National Gauge Factory was established at Kilburn, and was regarded financially as an adjunct of the Wolseley factory. The Fairfax Factory was managed by Mr. W. T. Bassett Lowke, who was experienced in gauge work, and employed 15

[1] Vol. VIII, Part III, Chapters I and II; Hist. Rec./R/400/57. (Printed) *Weekly Report, passim.*

skilled enemy mechanics, who produced a satisfactory output. The output from all these factories except that at Birmingham, from which the main output was small tools, taps and dies, was sent to the National Physical Laboratory, Teddington, where the gauges were invoiced at cost, plus 10 per cent. profit. Most of the gauge factories involved a capital expenditure of slightly over £20,000 each. After the Armistice they either continued gauge manufacture, chiefly for aircraft work, or were turned over again to their normal work. The Fairfax factory was closed and the workers reinterned.

The supply of small tools fell considerably short of the requirements at the beginning of 1916, and though no general control of the small tool trade was instituted until later, various firms were induced to extend their works, and in one instance new plant was set up for the State manufacture of tools which were particularly difficult to supply. This was the new National Tool Factory at Gateshead. The Ministry also took over the direction of the Coats Machine Tool Company's works at Westminster, on the ground that the inferior quality and high cost of the output was due to mismanagement; it appointed a managing director, and became responsible for working expenditure. The Gateshead factory began production of spade-cutters in August, 1916, and reached its estimated output of 3,000 cutters a week by the end of the year, while subsequent extensions enabled this quantity to be increased to 5,000 per week. Dilution was extensively carried out, and the financial results attained were excellent. The Coats Machine Tool Company's factory produced tools of all kinds, and by 1917, after the reorganisation by the Ministry, its weekly output was valued at £800 to £1,000. In September, 1917, the works of the Hoffman Manufacturing Company at Chelmsford, which were producing ball-bearings on a large scale, became a national factory. The business was bought up by the Ministry as, in view of its post-war prospects, the firm was unwilling to extend the factory any further to meet the needs of the new aircraft programme, while difficulties as to future commercial competition prevented the firm's exceptional technical abilities being used for the benefit of other factories. The managers placed their services at the disposal of the Ministry. The estimated cost of purchase in March, 1918, was £1,500,000. Under the control of the Ball Bearings Branch, working in close connection with the Aircraft Supplies Department, the two managing directors continued to work the factory as agents for the Ministry. A high standard of efficiency was maintained throughout the war, the output being steadily increased from some 72,000 bearings monthly early in 1915, to 230,000 in October, 1918.

In the autumn of 1918[1] the total number of employees in all these factories, excluding Chelmsford, was about 1,600, of whom 25 per cent. were women. The capital expenditure on the factories, exclusive of Chelmsford, was £95,600 to 31 March, 1919.[2]

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[1] The figures taken for Birmingham, Kilburn and Walthamstow, are for March, 1918, the latest available.

[2] The figures for Pimlico are for March, 1918.

A list of the national gauge and tool factories is given below :—

Factory.	Administration.	Date of Establishment or Nationalisation.
National Gauge Factories—		
Woolwich	Messrs. Pitters Ventilating and Engineering Company.	1915
Croydon	Vidal Engineering Company ..	1915
Birmingham ..	Messrs. Chatwin	1915
Pimlico	Wolseley Motor Company ..	1917
Kilburn (Fairfax) ..	Direct Control	1917
Walthamstow ..	Newall Engineering Company ..	1918
National Tool Factories—		
Gateshead (spade-cutters).	Direct Control	1916
Westminster (small tools).	Coats Machine Tool Company ..	1917
Chelmsford (ball-bearings).	Hoffmann Manufacturing Company.	1917

II. National Factories for Salvage, Repair, and Rectification.[1]

The responsibility for the repair of *matériel* returned as salvage from the battle area was at first vested in several different departments of the Ministry. Thus, all material was first received and sorted by the salvage depôts, established at several towns on the coast by the Salvage Department. The actual work of repairing or re-manufacture was undertaken to a large degree by contractors as a subordinate part of their whole programme. A rapidly increasing amount was done by the National Box Factories,[2] controlled by the Timber Supply Department; ammunition and boxes were repaired in the State factories at Dagenham Docks and Newport (Mon.), under the administrative control of the Small Arms and Small Arms Ammunition Department, and boxes for bombs and grenades were dealt with at Beddington National Box Repair Factory established by the Trench Warfare Department. Gun carriages were repaired at the National Gun Carriage Repair Factory, Southampton, under the control of the Gun Manufacture Department, and fuses were rectified in a factory in Gray's Inn Road, administered by the Shell Manufacture Department. At the end of 1917 a reorganisation of administration resulted in a closer co-operation of Salvage and Stores Departments under one controller.

[1] M.C. 62, 244, 456; Hist. Rec./R/1122/20; Vol. XI., Part I, Chap. II, Appendix IV; Hist. Rec./R/400/57; D.G.I.M./General/402; C.G.M. 387 Q.
[2] *See* below p. 219.

The five depôts controlled by the Salvage Department were placed at Blyth, Immingham (near Grimsby), Trafford Park (near Manchester), Renfrew and Ridham. Little constructional work was required, as in most cases land was either taken over under the Defence of the Realm Act, or was lent to the Ministry by the owners for a specified time, and where existing accommodation could not be adapted to the new purpose, buildings of a temporary nature were rapidly erected. The depôts were occupied in receiving, storing and sorting Q.F. cartridge cases and boxes, heavy artillery ammunition components and anti-gas equipment, and in despatching them to various stores and factories in accordance with the allocations received from the Stores Departments concerned. In June, 1918, the number employed in four of the five factories[1] only totalled 1,268, and of these, some 75 per cent. were women. Unlike most of the national factories the salvage depôts were required to continue work after the cessation of hostilities with probably increased labour, as more shipping facilities, on which their work was entirely dependent, would then be available for transport from the various fronts. The capital expenditure on all five up to March, 1918, amounted to £59,100.

The National Cartridge and Box Repair Factories at Dagenham and Newport acted as receiving depôts for salved munitions, and also carried on the work of rectification on a large scale. The Dagenham factory was at work early in 1916, but at the end of the year extensions to the factory were made, and female labour introduced, so that by the spring of 1917 the combined programme of the two factories provided for the repair of 650,000 18-pdr. cartridge cases, 100,000 4·5-in. cartridge cases, and more than 175,000 ammunition boxes per week. Much difficulty was experienced in finding skilled workmen, and men were imported from Ireland or lent by individual firms to push forward the work. In April, 1918, of 3,772 workers at the two factories, 88 per cent. were women. The capital expenditure on the two factories was £438,300 in March, 1918.

Buildings at Beddington, near Croydon, were rented in November, 1916, by the Trench Warfare Supply Department and converted into a National Box Repair Factory for the repair of bomb and grenade boxes. Work was started early in 1917, and by September, 15,000 boxes were repaired each week, practically all the workers being women. In October, 1918, female labour represented 89 per cent. of the total number employed (318). The cost of repairing was halved by April, 1917, and the total expenditure on land, buildings and plant amounted to £7,200.

The National Gun Carriage Repair Factory at Southampton was transferred to the Gun Department at the beginning of 1918. The factory had been used for some time by the Carriage Inspection Department, Woolwich, as an inspection depôt for the sentencing of carriages returned from overseas, and had been extended at a cost of £6,500. Repair work started in the spring of 1918, and after a few months

[1] Renfrew was temporarily closed.

20 carriages a week were being turned out. The repair of breech mechanisms was also undertaken. There was no lack of labour at Southampton, and when the Ministry took over the factory, only 2 per cent. of the employees were women. This percentage was, however, raised to 30 by the end of October, 1918, when the total number of employees was 174. The capital expenditure to 31 March, 1919, amounted to £18,600.

Fuse rectification was carried out at the National Fuse Rectification Factory, Phœnix Place, Gray's Inn Road.[1] The premises were taken over under the Defence of the Realm Act, at the beginning of May, 1916, additional accommodation in an adjacent garage being taken later. Messrs. William Cubitt, who were already rectifying fuses in their works in Gray's Inn Road, undertook as agents of the Ministry, to alter, equip and manage this factory, for the conversion of American supplies of the No. 100 fuse to No. 102. An agreement was concluded in October, 1916, providing that all production costs should be paid by the Ministry and the firm should receive as a fee 10 per cent. of such costs. A sum of £10,150 was to be paid the firm for expenditure on equipment, etc., and a further sum of £3,300 was subsequently sanctioned for additional alterations. At the end of 1917, the factory changed over to the conversion and rectification of fuse No. 101 and the original agreement was modified, a fixed sum of 1d. a fuse being paid to the firm instead of a percentage. Other work done included the hardening of stocks of soft steel needles for fuses. The employees in October, 1918, numbered 522, of whom 70 per cent. were women. The capital expenditure to March, 1919, amounted to £22,500.

A list is given below of the national factories for salvage, repair and rectification, which with the exception of the Fuse Rectification Factory, were under the direct control of the Ministry.

Factory.	Purpose.
Government Salvage Depôts—	
Blyth	Receiving, sorting and dispatching salvage.
Immingham	
Renfrew..	
Ridham	
Trafford Park (Overseas Salvage) ..	
National Cartridge and Box Repair Factories—	
Dagenham Dock	Receiving and repairing ammunition and boxes.
Alexandra Dock, Newport	
Beddington (Trench Warfare) ..	Repairing bomb and grenade boxes.
National Gun Carriage Repair Factory—	
Southampton	Repairing gun carriages.
National Fuse Rectification Factory—	
Phœnix Place, London	Conversion and rectification of Fuses No. 100 and No. 101.

[1] 15/Muns./2554, 94/F./1259.

III. National Box Factories and Sawmills.[1]

When the Ministry of Munitions became responsible for the supply of ammunition boxes, the patterns being made were still chiefly of the pre-war type, used for transport to the Colonies. New designs were then made for less expensive and elaborate types and contracts placed with various wood-working firms. Supply was arranged on the open tender system, which resulted in considerable disorganisation of plant and labour, by reason of the frequent changes made in the contracts placed with different firms. The Timber Supplies Department of the Ministry, therefore, established National Box Factories to avoid the difficulties involved in the contract system and to meet emergency demands for cases urgently needed. In addition to filling these requirements the National Box Factories, of which the first two were in operation by the end of 1916, also effected considerable economy by converting into the packages for which it was most suitable, timber returned by contractors as unsuitable for their particular work, and material obtained from boxes salvaged from abroad[2] or brought into the country as packages for overseas supplies. In many cases buildings were taken over in proximity to the filling factories and undertook the repair of transit cases used by the latter.

The London area was served by the first two factories at Deptford and Woolwich, and in January, 1917, a large factory at Willesden, near the Park Royal inspection works, was purchased from the Standard Woodwork Company. In April, 1917, work began at Erith and Willesden on non-returnable boxes from overseas, which were either repaired for re-use, or converted into caseboards for new boxes. This proved to be a most successful section of the work, and some 400 tons of timber was utilized each week. By October, 1917, ten National Box Factories were at work, and boxes were being broken down at the rate of 80,000 per week, yielding approximately 200 standards of usable timber. Although more skilled tin-workers were available in the North of England, tin or tin-lined packages were first repaired at Deptford to avoid the transport of salvage landed in the South to the North and back again, most of it being re-despatched from London. In 1918, additional factories were taken over for this work at Maidstone, Guildford, Luton, and Paisley. Delays occurred at the box-factories from time to time, owing to the congestion at the ports, and the time required to sort out salvaged components which were returned in the boxes, but the output generally was very satisfactory. During the spring, some of the factories were concentrated on cordite cases and boxes required by the Trench Warfare Department for various explosives, and on other urgent work. Extensive dilution was effected, the percentage of female labour to the whole number employed

[1] HIST. REC./H/1860/5; HIST. REC./R/400/57, 1122/10, 20; S.M.I./466; D.D.G.E./E.M.5/68, 1; D.G.I.M./Gen./402.

[2] *See* under Salvage and Rectification Factories. (p. 217 above.)

being in many factories as high as 87 per cent. In October, 1918, of the total number (approximately 2,300) employed in 14 of the factories, 69 per cent. were women.[1] In nearly every case, except at Willesden, factories previously engaged in various kinds of woodwork were taken over by the Ministry as "going concerns," being rented for a period slightly longer than the duration of the war. The majority of the factories were directly controlled by the Timber Supplies Department of the Ministry, although where possible members of the existing staff were retained under the supervision of an official appointed by the Ministry, but in some cases the original owners continued to manage the works as agents for the Government. The capital expenditure on all the factories up to 31 March, 1919, amounted to approximately £66,000.

The caseboards for 18-pdr. and 4·5-in. shell boxes were imported, but to supply timber for urgent requirements and for miscellaneous packages, sawmills were taken over by the Ministry. In September, 1917, one national sawmill in England and three in Scotland were at work, and in October and November of that year, when the Timber Supply Department of the Board of Trade had instituted more extensive felling operations, additional mills were acquired at Luton, Southampton, Poole, Gloucester and Warrington as well as three more in Scotland. Early in 1918 a further factory was started up at Berwick-on-Tweed.

Practically all the original owners of the sawmills continued to work as Government agents; timber was supplied by the Ministry and an inspector was placed in each mill to ensure that the stocks received were properly accounted for and cut as required. The chief difficulty found in utilizing home-grown timber was the problem of drying the wood sufficiently in a short time. For this purpose drying kilns were erected, first in the Glasgow and London areas and later in connection with most of the larger sawmills, but many were not ready for use until the summer of 1918. The output of caseboards suitable for boxes was retarded in 1918 by the poor quality of the timber supplied to the mills, and by the great difficulty experienced in obtaining labour. At Luton Austrian prisoners were employed, while at many factories the lighter sawing was done by women. In the autumn of 1918, of 1,200 employees in the factories, 650 (53 per cent.) were women. The caseboards produced in the national sawmills were 8 to 10 per cent. less expensive than those purchased from overseas. After the Armistice, practically all the box-factories and sawmills with the exception of Willesden, reverted to their pre-war owners who turned over again to their normal production. The capital expenditure on the twelve mills at work in the summer of 1918, amounted to £30,481 by March, 1918, and to £81,300 a year later.

[1] No figures are available for Luton and Maidstone. The figures taken for Guildford and the two Paisley factories are those for April, 1918, the latest available.

The following list shows the chief national box-factories and sawmills under the control of the Ministry :—

Factory.	Administration.	Date of Establishment or Nationalisation.
Box Manufacture and Repair—		
Castleford	Direct Control	1917
Leeds	Messrs. J. H. Abrahams ..	1917
Letchworth	Co-Partnership Company, Ltd.	1917
Liverpool	Direct Control	1917
Luton	Direct Control	1918
Paisley No. 1	Direct Control	1917
Willesden	Direct Control	1917
Woolwich	Messrs. W. Watt Torrance and Company.	1916
Tin Box Manufacture and Repair—		
Deptford No. 1	Direct Control	1916
Deptford No. 2		1917–18
Glasgow ..		1917
Guildford ..		1918
Luton		1918
Maidstone ..		1918
Paisley No. 2 ..		1918
Non-Returnable Box Depôts—		
Erith	Direct Control	1917
Willesden ..		
Sawmills—		
Berwick	Messrs. Allan Brothers ..	1918
Dumfries	—	1917
Elgin	Messrs. A. Watson & Company	1917
Glasgow	A. McDougall's Timber Company.	1917
Glasgow	Messrs. J. Smellie & Company	1917
Gloucester	Messrs. Joseph Griggs & Company.	1917
Inverness	Messrs. J. Walker & Company	1917
Kilmarnock	Messrs. Brownlie & Company	1917
Luton	Messrs. Henry Brown & Sons	1917
Poole	Messrs. J. T. Sydenham & Company.	1917
Rotherhithe	Messrs. Priddy & Hale ..	1917
Southampton	Messrs. Driver & Company ..	1917
Warrington	Messrs. R. A. Naylor, Ltd. ..	1917

IV. Cowley Mine Sinker Assembly Station.[1]

Early in 1917, the Trench Warfare Supply Department undertook to meet an urgent Admiralty demand for mine sinkers. Owing to the difficulty of placing orders for complete sinkers, it was decided to

[1] HIST. REC./H/1600/6; HIST. REC./R/400/57.

produce the bulk of the requirements on the group system and assemble the parts at a central station. At the end of March, a central assembling station was established at Cowley near Oxford, in the works of Messrs. W. R. M. Motors Ltd., a firm experienced in trench warfare work.

A large empty building, 240 ft. by 135 ft., was available, and part of the firm's main works were also used. By the agreement with the firm, rental based on the assessment value was to be paid for a period of three months from 25 March, 1917, and thereafter subject to one month's notice on either side. The work of assembly was to be carried out under the direct supervision of Mr. W. R. Morris, of the firm whose works were used. The services of the works manager and office staff were also to be available, and a proportion of their salaries to be paid by the Ministry. All outgoings, including wages, were to be borne by the Ministry.

Little structural alteration was necessary, but a considerable amount of equipment had to be supplied at government cost. At the end of August, some additional accommodation was found to be necessary for inspection purposes. Sidings were constructed on the Great Western Railway, communication with the assembly station being affected by means of a narrow-gauge railway.

Delivery of complete Mark VIII sinkers began at the end of August, 1917; an output of 750 a week was reached by October, and was maintained at that rate. At the beginning of 1918, a slightly different type, Mark VIII*, was undertaken, entailing some re-organisation.

In January, 1918, the employees at the assembly station numbered 411, 36 per cent. being women, but by the autumn the amount of work to be done had been reduced and numbers had fallen to 246, of whom 76 were women. The capital expenditure up to March, 1918, amounted to £21,600.

V. The National Machine Gun Factory, Burton-on-Trent.[1]

In the autumn of 1917, when a review of the requirements of machine guns for 1918 showed that the increasing output from existing factories would not be adequate to meet the greatly increased demands made by the extended programmes of air and tank warfare, the project of setting up a national factory for the production of machine guns was considered. The scheme, as suggested at a specially convened sub-committee of the Munitions Council in September, 1917, provided for the erection of a factory outside the day air-raid area with a producing capacity of 400 machine guns per week. The project received Treasury sanction on 25 October, 1917, and arrangements were at once made for carrying it into effect.

A site was chosen at Burton-on-Trent, where 153 acres were acquired for the factory from the Marquis of Anglesea by private treaty. The factory was planned for construction on the most rapid lines, being built of brick, steel framed, part plaster, part board with

[1] Hist. Rec./R/1122/45; 1410/2, 13; M.C. 20; D.G.F./M.G.F./33; D.D.G.E./E.M. 8/475, 495.

slate roofs. The contract for construction was given to Messrs. Thomas Lowe & Sons. By March, 1918, building was progressing satisfactorily, and plant, tools and fixings had been ordered. When the Armistice was declared, the factory was still in course of construction, and the first output was not secured till the week ending January 4, 1919, when repaired machine guns began to be delivered.

The management of the factory was put in the hands of a superintendent, Colonel Mills, appointed by the Government, and a small staff. As labour was not required for working machines at this factory until after the Armistice the problem of securing sufficient workers did not arise. All labour difficulties at Burton were concerned with protests made by the local Trades Council in May, 1919, against the closing of the works.

In May, 1919, orders were given for the closing down of the factory as a working unit, and for its conversion into a store for guns and machinery. Accordingly in May and June arrangements were made for carrying out these orders, and the factory was closed down.

Before the decision to close Burton had been made final, the plan for the disposal of the works was a matter of considerable discussion. It was suggested that Burton should be kept as a working unit for production and repair of machine guns in order that a permanent centre of trained machine workers and running machines might be provided from which expansion would be possible in case of emergency. The experience of 1914, when the lack of skilled workers had been a severe check on production, made evident the need for some centre for training workers in machine-gun production if such delays were to be avoided in the future.

While this proposal received serious consideration it was decided that the expense which it involved would be too great to justify it. The shops at Woolwich and Enfield could be adapted to the manufacture of machine guns should need arise, and there was strong probability that a new design of gun would be evolved before any considerable demand would again be made, and therefore that the skilled labour and machinery producing one type of machine gun at Burton might fail to be of the advantage that was expected by the promoters of the scheme.

The probable cost of the factory had been estimated in September, 1917, as £750,000. By the end of 1919 the total actual capital outlay on construction, plant, etc., was estimated at £879,581, with the addition of £12,829, the cost of the site, bringing the total up to £892,410 for the complete undertaking.

VI. National Factories for Optical Munitions.[1]

The Kentish Town Factory.

Before the outbreak of war, very few firms in England were engaged in the manufacture of optical instruments, and to meet the demands of the services considerable extensions of existing plant had to be

[1] Vol. XI, Part III, Chap. II; O.M.G./Gen./2305, 3210.

carried out, but no national factory was established until the end of 1917. The demands were then greatly increased and the Periscopic Prism Company, on which the Ministry was largely dependent for supplies, found it impossible to cope with the proposed programme for 1918 unless extensive additions were made to its factory at Kentish Town. The company, therefore, applied to the Ministry for financial advances. The additional capacity was urgently needed to supply optical sights for aeroplane guns, telescopic sights for rifles, gun-sighting telescopes for the Admiralty, and other types of optical instruments. The organisation and experience of the management were most satisfactory and it was accordingly decided to take over the factory entirely, bringing both the original works and the new extensions under the control of the Ministry. The shares of the company were bought up, although the business was still retained in the form of a limited liability company, and thus from 28 February, 1918, the factory was brought under the control of the Controller of Optical Munitions, Glassware and Potash Production Department, three Directors being appointed to manage the works on behalf of the Ministry.

Plans were submitted for new buildings on adjoining land belonging to the factory, but considerable delay occurred in the construction until August, after which better progress was made and the output materially increased, instruments of various kinds being produced to the value of some £100,000. The cost of the extensions to the works carried out during the summer amounted to approximately £46,100 and the total cost of taking over the company involved some £80,000.

In May, 1918, the employees numbered 204, 43·6 per cent. being skilled men, and 31·8 per cent. women.

National Photographic Lens Factory, Brimsdown.

In 1918, further plant for photographic lenses was set up by the Ministry at Brimsdown near Enfield. The large quantities of lenses required for the Hythe Gun Camera evolved by the Air Force, had been for a considerable period produced in France. In 1918, owing to various manufacturing difficulties, including the scarcity of coal, production in France became impossible and as English lens manufacturers were already working to their full capacity the National Photographic Lens Factory was established. Mr. Emerson of the Guaranteed Lens Company, who had much experience in lens production, undertook to manage the factory for the Ministry, and the freehold of suitable premises at Brimsdown was purchased. After some delay, the factory was started up, the first lenses being delivered in July, 1918, and supplies continued to be delivered regularly until the Armistice.

The capital expenditure was estimated in July as approximately £3,000. The actual expenditure to 31 March, 1919, amounted to approximately £6,000.

VII. National Concrete and Steel Billet Breaking Factories.[1]

Early in 1918, owing to the difficulties experienced in the construction of new factories and depots, two national factories for concrete and plaster slab production were established by the Steel and Iron Department of the Ministry, to provide some of the materials required for large building operations.

At Gotham, in Nottinghamshire, land was leased by Messrs. King & Company for the erection of a new factory, the cost of building and equipment, which by 31 March, 1919, amounted to £16,600, being borne by the State, while the firm had the option of taking over the factory after the war at an agreed valuation.

At Yate, near Bristol, a factory was erected and managed by Messrs. Robert McAlpine & Sons, as agents for the Ministry. An official of the firm was appointed as manager, and as he devoted a part of his time to administrative work at the neighbouring Western Aircraft Repair Depot, which was also controlled by the firm, the administration and financial control of the factory and depot were not at first entirely distinct. The factory produced huts, walls, ferro-concrete fence posts, or poles for carrying electric cables, chiefly for use in the erection of new national establishments, and production had begun by June, 1918, although some construction was still in progress, and some difficulty had arisen in connection with railway facilities. The number of employees at this date was 125 men and 15 women. The original estimated capital expenditure was £20,000, but in June it seemed probable that this sum would be considerably exceeded. The actual sum expended by 31 March, 1919, was £39,700.

Two other national factories (as distinct from mines and quarries) were controlled by the Steel and Iron Department. The one was the Billet-breaking Factory, at Trafford Park, Manchester. This was established at the end of 1916, to deal with the steel billets, then shipped from America. The specification for shell steel required that all billets or bars should be broken to shell lengths to ensure soundness on inspection, and as sufficient capacity was not available at contractors' works to cope with the imported billets, plant was set up for the purpose at Manchester and the National Projectile Factory, Lancaster. The Trafford Park Factory, at Manchester, was erected next to the Ship Canal, by which the steel was brought from Liverpool, and was directly controlled by the Ministry. It contained the largest billet breaking plant in the country and accounted for 7,000 of the 14,000 tons which represented the average weekly amount of steel imported from America, the remaining 7,000 being distributed between the Lancaster Factory and various contracting firms. Sufficient broken billets were despatched each week from Trafford Park to the forgemasters and national factories for the manufacture of 150,000 shells of all sizes between 18-pdr. and 9·2-in. The number of employees in October, 1918, was 529, and the percentage of women was 21·6. The capital expenditure on the factory to March, 1918, was £142,200.

[1] HIST. REC./H/1810/5 ; D.F.C./C/57 ; HIST. REC./R/1122/20, 45.

At Merthyr Tydfil, rolling mills were established at State expense in connection with the blasting furnaces of Messrs. Crawshay Brothers, which were also taken over by the Ministry, and worked under an agency agreement for the period of the war and six months after. The works were originally engaged in producing basic pig from native ores, and, during the war, rolled 18-pdr. H.E. shell-steel bars from American ingots. The total number employed in the blast furnaces, rolling-mill and engineering shops was 904, of which less than 1 per cent. were women. Up to 31 March, 1918, £26,500 had been expended on the blast-furnace, and £51,800 on the rolling-mills.

The following is a list of the national factories controlled by the Steel and Iron Department of the Ministry for various purposes :—

Factory.	Administration.	Purpose.
Gotham.. ..	Messrs. J. A. King & Company	Manufacture of plaster slabs.
Yate	Messrs. Robert McAlpine & Sons.	Manufacture of concrete slabs.
Trafford Park (Manchester)	Direct Control	Steel billet-breaking.
Merthyr Tydfil..	Messrs. Crawshay Brothers, Ltd.	Rolling mills and blast furnaces.

VIII. National Chemical and Anti-Gas Factories.[1]

National Factories for Chemical Manufacture.

In the spring of 1915, the first demands for chemical supplies were met by extensions to the works of existing manufacturers, and, with the exception of the Admiralty Factory at Stratford, which was occupied largely upon experimental work, no Government factories were established for chemical manufacture until April, 1918, since the experience and practical knowledge of chemical firms were essential to the successful development of new plant. In April, 1918, responsibility for chemical warfare supplies was transferred to the Explosives Supply Department, partly to facilitate the use of spare capacity in National Explosives Factories for poison gas production. The policy of this department was to produce the large quantities of arsenic compounds and mustard gas then required in state factories, since existing trade capacity was by that date fully absorbed. The greater part of the capital outlay upon national plant for the production of lethal substances was incurred in the conversion and installation of plant for the manufacture of mustard-gas and arsenic compounds during the year 1918. It was estimated that the cost of the scheme for producing these two classes of chemical would involve an outlay of £394,500 upon national factories.[2] Of the factories previously engaged on the manufacture of explosives, H.M. Factories at Sutton Oak and

[1] *See* also Vol. XI, Part II, Chap. III and IV.
[2] X/CW/709.

Ellesmere Port,[1] formerly manufacturing synthetic phenol, were converted at a cost of some £59,500, for the production of arsenic compounds. Output from the former began in May, 1918, but bulk production was not reached until November, 1918. The total output was 60 tons. In July, 1918, H.M. Factory, Ellesmere Port, was expected to have a capacity of 40 tons weekly, and in view of the urgency of the demand, military labour was employed to hasten both the construction and the operation of the new plant. Nevertheless, actual output fell far below the estimated capacity. A small factory at Rainham, belonging to the South Metropolitan Gas Company, was brought under the direct control of the Ministry during the summer of 1918, and was converted for the production of arsenic compounds, at a total cost of £40,200.

The largest national factory which was established for chemical manufacture at this time was H.M. Factory, Avonmouth, which was originally planned as a picric acid factory, and was turned over to the production of mustard gas, in June, 1918.[2] As a part of the same scheme for the manufacture of large quantities of mustard gas, the erection of an agency factory at Langley was begun in the spring of 1918, for producing the solvent, carbon tetrachloride. This factory was completed and operations began in September, 1918, although benzol had replaced carbon tetrachloride as a solvent in mustard gas manufacture, and the output of the factory was subsequently intended for naval purposes and for satisfying French demands, which would otherwise have been met in chlorine.[3] The capital expenditure on this factory was about £117,300.

In August, 1918, steps were taken to nationalise the works of Messrs. Electro Bleach and By-Products, Ltd.,[4] at Middlewich, owing to the unsatisfactory nature of their output. The company had erected this factory in 1917, on land adjoining their existing works, and the capital outlay had been borne by the State. The new factory had then been laid out for the manufacture and charging of 10 tons of phosgene and the liquefaction of 20 tons of gaseous chlorine per week. When it was taken over in 1918, it proved impracticable to make an absolute distinction between the national plant and the firms' works, from which power, light and transport facilities were derived, but the thorough re-organisation which followed the establishment of direct control over the poison-gas factory resulted in a very greatly increased output and a higher standard of work. From August to November, 1918, the output of phosgene was raised from an average of about three tons weekly to a quantity little less than the full estimated capacity of 10 tons weekly, while the proportion of the charged shells which were rejected on inspection was reduced from 7 per cent. to 5 per cent.

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[1] Hist. Rec./H/1122/13.

[2] For an account of this factory, *see* above p. 49.

[3] X/CW/709.

[4] Hist. Rec./H/1122.7/14.

Owing to the peculiar nature of the work upon poison-gas manufacture, the employment of skilled men of good physique was imperative, and the dilution of labour was difficult. In the autumn of 1918, the total numbers employed in State factories for the production of lethal substances, were 1,422, of whom 244 alone were women. This figure excluded the comparatively small factories at Rainham and Langley.

National Factories for Gas-charging.

Owing to the difficulty of transporting poisonous substances, the work of charging them into shell was undertaken, wherever possible, at the place of manufacture. The first separate venture for the charging of projectiles was the trade factory established at Walthamstow in 1915, and subsequently nationalised. For a considerable period, it was engaged also upon the head-filling of chemical shell, of which work an account has already been given.[1] Messrs. Ardol's factory at Selby,[2] was taken over by the Ministry in June, 1916, and carried out shell charging and the production of hydrogen and hydrogenated oils. This factory was not brought under direct control but was administered under an agency agreement.

In addition to the British factories, plant was set up at Calais in March, 1916, for charging phosgene, supplied by the French, into cylinders, 3,400 cylinders being delivered weekly. The charging factory was worked at first by from 30 to 40 English civilians, and subsequently by a military party from the Special Brigade under the supervision of an official of the Chemical Supply Section.

Owing to the undesirability of introducing explosives into the factories where the chemicals were manufactured and charged, the process known as filling, *i.e.*, the insertion of the bursting-charge into the shells already charged with chemicals, was not undertaken as a rule by contractors or national chemical factories, but the charged shell were sent to Greenford,[3] where a factory was erected in 1916, solely for the filling and assembling of chemical shell.

Spare capacity in the National Filling Factories was adapted towards the end of the war for the charging of shells with mustard-gas as well as for the head-filling and assembling of these and other chemical shells. From July to November, 1918, 85,424 6-in. shells were charged at the factory which was specially erected for this purpose at Chittening, and 82,000 4·5-in. and 220,000 18-pdr. shells were charged at Banbury. The Hereford Filling Factory began charging in October, 1918, and completed 3,000 4·5-in. and 1,000 18-pdr. shells by November. At Chittening the filling, as well as the charging, of shell was undertaken, but most of the shell charged at Banbury and Hereford were sent to Hayes National Filling Factory to be filled. The work carried out in the filling factories has already been described.[4]

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[1] *See* above p. 184.

[2] D.E.S./C.W./169; T.W. 6161.

[3] *See* above p. 183.

[4] *See* above p. 156.

The Salvage Depôt, Bucknall.

It was eventually found necessary to nationalise the depôt, which was engaged in recovering chemicals from returned and rejected cylinders, since the operations involved were peculiarly difficult and entirely experimental and the irregularity of the work hampered the settlement of contract terms. The risk of injury to the workers, through escapes of gas, was also peculiarly great. The depôt had been established in 1916, by the Bucknall Sawmills Company. The capital expenditure was borne by the Ministry, and the depôt was operated under an agency agreement until June, 1917. It was brought under direct control in July, 1917, with a view to increasing efficiency and economy. The capital expenditure on the depôt down to March, 1919, was £11,500.

National Factories for Anti-Gas Apparatus.

The first committees appointed, after the German gas offensive in April, 1915, to deal with supplies of defensive apparatus, placed all the work with contractors, and no national factory was established until late in 1916, although a certain amount of cutting and sewing was carried out in factories controlled by the Royal Army Clothing Department. The first anti-gas factory to be set up directly under Government control was at Stamford Hill, where the L.C.C. Stores Depôt was acquired in 1916, and fitted up as a granule factory on the model of Messrs. Boot's factory at Nottingham. Before production started a new formula was introduced, and further plant was erected to produce the new F. granule. In February, 1917, the factory started operations under the control of the Anti-Gas Department (then a section of the War Office and subsequently transferred to the Ministry), and continued until the Armistice, the maximum output obtained from a day and night shift being 30 tons weekly. In August, 1918, the Ministry opened new factories at Batavia Mills and Holloway Mills, Holloway, which were directly controlled by the Department, for the manufacture of "Green-Band" respirators, the total number produced by 11 November being 55,140, in addition to a large number of spare parts.

Although the national works which were actually established for the manufacture of anti-gas apparatus were thus strictly limited in number, a very great part of the production took place in numerous factories which were controlled by two firms under contracts which very nearly approached the form of an agency agreement. These firms, Messrs. John Bell, Hill and Lucas, and Messrs. James Spicer and Sons, not only manufactured apparatus and components in their own factories, but also supervised production by a large number of contractors' works, mostly in the neighbourhood of London.[1]

The following list shows the national factories which were actually employed on chemical or anti-gas work, with the exception of inspection

[1] For a detailed account of their work, *see* Vol. XI, Part II, Chap. VI.

and storage depôts controlled by the Anti-Gas Department, where a certain amount of minor work, such as repairing, took place.

Factory.	Purpose.	Date.[1]
Manufacture of Chemical Substances.		
H.M. Explosives Factory, Sutton Oak.	Arsenic Compounds ..	March, 1918. (*See* above p. 76.)
H.M. Explosives Factory, Ellesmere Port.	Arsenic Compounds ..	July, 1918. (*See* above p. 54.)
H.M. Explosives Factory, Avonmouth.	Mustard Gas	June, 1918. (*See* above p. 49.)
H.M. Factory, Langley ..	Carbon tetrachloride ..	1918.
H.M. Factory, Middlewich..	Manufacture and charging of phosgene; liquefaction of chlorine.	August, 1918.
H.M. Factory, Rainham ..	Manufacture of arsenic compounds.	1918.
Charging with Chemical Substances.		
T.W. National Factory, Walthamstow.	Charging lachrymatory grenades, shells and projector-drums; head-filling lethal shells.	June, 1916. (*See* above p. 184.)
T.W. Factory, Calais ..	Charging cylinders and projector-drums.	March, 1916.
T.W. Factory, Selby (Ardol, Ltd.).	Charging Russian shell.	June, 1916.
H.M. Factory, Chittening ..	Charging and head filling mustard gas shells.[2]	1918. (*See* above p. 181.)
National Filling Factory, Banbury.	Charging and head filling and assembling mustard gas shells.[2]	1918. (*See* above p. 159.)
National Filling Factory, Hereford.	Charging and head filling and assembling mustard gas shells.[2]	October, 1918. (*See* above p. 167.)
Salvage.		
Bucknall Cylinder Depot ..	Evacuating and refitting cylinders.	July, 1917.
Manufacture of Anti-Gas Apparatus.		
L.C.C. Stores Depot, Stamford Hill.	Producing granules ..	1916.
Batavia Mills, Holloway ..	Making "Green Band" Respirators.	August, 1918.
Holloway Mills, Holloway ..	Making "Green Band" Respirators.	August, 1918.

IX. The National Rifle Factories at Birmingham.[3]

Two national factories for the manufacture of the Farquahar-Hill automatic rifle were established at Birmingham in 1918. The National Rifle Factory No. 1 consisted of buildings in Lench Street, the main

[1] Of erection, nationalisation or conversion to chemical work.
[2] For the factories engaged solely upon head-filling or assembling chemical shells, *see* above p. 156.
[3] M.C. 680; D.D.G.E./E.M. 3/1009; D.D.G.E./E.M. 9/75.

part of which was originally a small arms factory operated by the Standard Small Arms Company in connection with the component pool for rifle manufacture. It also included premises on the opposite side of the road, which had originally been built as an extension to the company's shops and afterwards taken over by the Ministry of Munitions as a training school. The National Rifle Factory No. 2 was in Garrison Lane and had been built shortly before by Messrs. W. Greener for the manufacture of rifle-parts. A definite request for 100,000 Farquahar-Hill rifles was made by the Army Council on 3 May, 1918. It was immediately decided that manufacture should be carried out on a peddled scheme, that the Lench Street Factory should make the more complicated parts and assemble the rifles, and the Garrison Lane Factory should make the barrels upon plant already existing there and to be removed thither from Lench Street.

Rifle manufacture requires special skill and experience, and until this date the production of complete weapons had been confined to the Royal Small Arms Factory at Enfield and experienced contractors. The supply of the new automatic rifle involved experimental manufacture, normally undertaken at Enfield; but circumstances made any further extension of that factory difficult, its utilization would have seriously affected the output of standard rifles, and its situation within the air-raid district made any expansion of its work undesirable. Most of the contractors engaged upon rifle and machine-gun manufacture were either unsuited for the new work or fully occupied. No complete drawings, and only one model rifle existed. The Standard Small Arms Company was peculiarly fitted to undertake the main part of the work, not only by reason of its experience in manufacturing for the component pool, but because the managing director had produced the first Farquahar-Hill rifles made and the company had assembled those of recent manufacture.

The scheme had necessarily to be financed by the Ministry, and an exact agreement was impossible to negotiate for so complex and novel a weapon. Accordingly, it was decided to purchase the factories from the two companies and operate them as national factories. Agreements as to the management were the subject of lengthy negotiation; but it was considered undesirable to take over the premises under the Defence of the Realm Act lest the goodwill of the management should be alienated. The general uncertainty as to the position seriously militated against enthusiasm and the operatives at the two factories became restless during the summer. Finally, on 16 October, 1918, the Army Council cancelled its demand for these rifles, in view of the impossibility of obtaining output in time to train the troops for the spring campaign. Steps were accordingly taken to close down the factories before any definite output had been attained. The capital expenditure upon both factories amounted to £166,500 by March, 1919.

APPENDICES.

APPENDIX I.

(CHAPTER III.)

Output of Empty Shell from National Shell Factories.

[Figures in Thousands.]

	1915.	1916.	1917.	1918.	Total.
Aberdeen—					
6-in. H.E.	—	—	34·6	65·1	99·7
Total	—	—	34·6	65·1	99·7
Ailsa Craig—					
4·5-in. H.E.	—	—	115·0	138·2	253·2
Total	—	—	115·0	138·2	253·2
Barnsley—					
4·5-in. H.E.	—	56·2	143·5	104·9	304·6
Total	—	56·2	143·5	104·9	304·6
Birmingham—					
18-pdr. H.E.	—	35·5	15·0	6·5	57·0
4·5-in. H.E.	—	296·6	687·0	752·7	1,736·3
9·2-in. H.E.	—	—	27·0	22·2	49·2
Total	—	332·1	729·0	781·4	1,842·5
Bradford—					
4·5-in. H.E.	14·0	180·0	247·6	212·4	654·0
4·5-in. Chemical ..	—	1·2	22·6	—	23·8
Total	14·0	181·2	270·2	212·4	677·8
Bristol—					
18-pdr. H.E.	39·4	858·5	1,111·2	1,024·1	3,033·2
18-pdr. S.	—	—	—	167·2	167·2
Total	39·4	858·5	1,111·2	1,191·3	3,200·4
Bury—					
18-pdr. Smoke ..	—	—	—	31·5	31·5
4·5-in. H.E.	—	9·5	32·9	69·5	111·9
Total	—	9·5	32·9	101·0	143·4
Cardiff—					
18-pdr. H.E.	3·2	35·2	187·2	272·3	497·9
Total	3·2	35·2	187·2	272·3	497·9
Cork—					
4·5-in. H.E.	—	—	10·4	21·8	32·2
Total	—	—	10·4	21·8	32·2

APPENDIX I—*contd.*

	1915.	1916.	1917.	1918.	Total.
Derby—					
4·5-in. H.E.	·4	150·0	258·4	137·5	546·3
4·7-in. Chemical ..	—	—	3·4	—	3·4
Total	·4	150·0	261·8	137·5	549·7
Dublin—					
18-pdr. H.E.	—	113·8	230·8	180·7	525·3
18-pdr. Smoke ..	—	—	—	12·4	12·4
9·2-in. H.E.	—	—	2·4	3·7	6·1
Total	—	113·8	233·2	196·8	543·8
Dundee—					
18-pdr. H.E.	11·5	201·8	339·1	8·7	561·1
2·75-in. S.	—	1·3	3·0	—	4·3
Total	11·5	203·1	342·1	8·7	565·4
E. Cumberland (Carlisle)—					
18-pdr. H.E.	—	40·5	99·5	164·6	304·6
18-pdr. Smoke ..	—	—	1·8	·2	2·0
Total	—	40·5	101·3	164·8	306·6
Ebbw Vale—					
18-pdr. H.E.	6·7	82·5	—	—	89·2
Total	6·7	82·5	—	—	89·2
Galway—					
18-pdr. H.E.	—	—	11·7	21·9	33·6
Total	—	—	11·7	21·9	33·6
Grimsby—					
4·5-in. H.E.	—	—	—	16·5	16·5
6-in. H.E.	1·0	65·9	143·2	108·2	318·3
Total	1·0	65·9	143·2	124·7	334·8
Hartlepool (Tyne and Wear)—					
8-in. H.E.	—	14·7	66·4	—	81·1
Total	—	14·7	66·4	—	81·1
Huddersfield—					
18-pdr. H.E.	3·1	64·3	182·7	220·0	470·1
Total	3·1	64·3	182·7	220·0	470·1

APPENDIX I—*contd.*

	1915.	1916.	1917.	1918.	Total.
Keighley—					
18-pdr. H.E.	23·6	188·3	127·6	149·1	488·6
18-pdr. Chemical ..	—	—	—	131·3	131·3
3·7-in. H.E.	—	—	140·3	11·9	152·2
6-pdr. A.A.	—	19·1	2·1	—	21·2
Total	23·6	207·4	270·0	292·3	793·3
Leeds—See under National Projectile Factories.					
Liverpool[1]—					
18-pdr. H.E.	45·3	746·4	562·5	500·2	1,854·4
18-pdr. Chemical ..	—	—	—	1·0	1·0
18-pdr. Smoke ..	—	—	10·5	8·0	18·5
2·75-in. H.E. ..	—	24·7	296·0	476·6	797·3
4·5-in. H.E.	—	18·1	28·0	—	46·1
60-pdr. H.E.	—	—	6·6	—	6·6
6-in. H.E.	—	52·5	187·0	192·4	431·9
8-in. H.E.	—	—	13·9	12·7	26·6
Total	45·3	841·7	1,104·5	1,190·9	3,182·4
Llanelly—					
18-pdr. H.E.	—	—	75·9	430·0	505·9
6-in. H.E.	—	44·4	256·1	364·9	665·4
Total	—	44·4	332·0	794·9	1,171·3
Manchester—					
4·5-in. H.E.	—	8·0	29·1	51·8	88·9
Total	—	8·0	29·1	51·8	88·9
Newport—					
60-pdr. H.E.	—	133·5	298·6	169·1	601·2
Total	—	133·5	298·6	169·1	601·2
North Wales[2]—					
13-pdr. H.E.	—	—	44·0	10·6	54·6
18-pdr. H.E.	—	22·7	318·1	490·6	831·4
18-pdr. Smoke ..	—	—	5·0	4·0	9·0
Total	—	22·7	367·1	505·2	895·0
Nottingham—					
13-pdr. H.E.	9·4	324·3	13·1	—	346·8
18-pdr. H.E.	—	—	543·3	564·1	1,107·4
18-pdr. Smoke ..	—	—	—	1·9	1·9
2·75-in. H.E. ..	—	46·7	7·3	—	54·0
Total	9·4	371·0	563·7	566·0	1,510·1

[1] Includes Haymarket, Cunard, Lambeth Road, and Chester.
[2] Includes Wrexham, Portmadoc, and Carnarvon.

APPENDIX I—*contd.*

	1915.	1916.	1917.	1918.	Total.
Rawtenstall and Bacup—					
4·5-in. H.E.	—	15·9	61·4	79·6	156·9
Total	—	15·9	61·4	79·6	156·9
Rochdale—					
6-in. H.E.	—	10·9	39·8	39·5	90·2
Total	—	10·9	39·8	39·5	90·2
Rotherham—					
4·5-in. H.E.	·7	82·6	156·9	174·2	414·4
4·5-in. Chemical ..	—	—	10·5	—	10·5
Total	·7	82·6	167·4	174·2	424·9
Swansea—					
18-pdr. H.E.	2·7	76·5	80·2	55·7	215·1
4·5-in. H.E.	—	51·4	198·0	170·5	419·9
Total	2·7	127·9	278·2	226·2	635·0
Uskside—					
18-pdr. H.E.	2·1	21·0	1·4	—	24·5
4·5-in. H.E.	—	—	—	16·1	16·1
6-in. H.E.	—	21·8	55·4	42·5	119·7
Total	2·1	42·8	56·8	58·6	160·3
W. Cumberland—					
18-pdr. H.E.	—	38·2	146·3	167·9	352·4
18-pdr. Smoke ..	—	—	3·5	3·5	7·0
Total	—	38·2	149·8	171·4	359·4
Totals—					
13-pdr. H.E.	9·4	324·3	57·1	10·6	401·4
18-pdr. H.E.	137·6	2,525·2	4,032·5	4,256·4	10,951·7
18-pdr. S.	—	—	—	167·2	167·2
18-pdr. Chemical ..	—	—	—	132·3	132·3
18-pdr. Smoke ..	—	—	20·8	61·5	82·3
2·75-in. H.E. ..	—	64·8	35·3	—	100·1
2·75-in. S.	—	1·3	3·0	—	4·3
3·7-in. H.E.	—	—	140·3	11·9	152·2
6-pdr. A.A.	—	19·1	2·1	—	21·2
4·7-in. Chemical ..	—	—	3·4	—	3·4
60-pdr. H.E.	—	133·5	305·2	169·1	607·8
4·5-in. H.E.	15·1	874·9	2,236·2	2,353·9	5,480·1
4·5-in. Chemical ..	—	1·2	33·1	—	34·3
6-in. H.E.	1·0	195·5	716·1	812·6	1,725·2
8-in. H.E.	—	14·7	80·3	12·7	107·7
9·2-in. H.E.	—	—	29·4	25·9	55·3
Grand Total ..	163·1	4,154·5	7,694·8	8,014·1	20,026·5

APPENDIX II.

(CHAPTER IV.)

Output of Empty Shell from National Projectile Factories.

[Figures in Thousands.]

	1915.	1916.	1917.	1918.	Total.
Birtley—					
4-in. H.E.	—	—	—	16·2	16·2
60-pdr. S.	—	44·1	145·9	271·0	461·0
4·5-in. H.E.	—	—	171·0	228·3	399·3
6-in. H.E.	—	93·9	507·9	690·2	1,292·0
8-in. H.E.	—	27·2	296·6	313·5	637·3
Total	—	165·2	1,121·4	1,519·2	2,805·8
Cardonald—					
18-pdr. H.E.	—	—	50·7	0·2	50·9
6-in. Chemical ..	—	—	—	319·8	319·8
8-in. H.E.	—	162·5	466·6	379·0	1,008·1
Total	—	162·5	517·3	699·0	1,378·8
Cathcart—					
8-in. H.E.	—	44·4	49·8	—	94·2
Total	—	44·4	49·8	—	94·2
Darlington—					
18-pdr. S.	—	—	454·4	609·4	1,063·8
6-in. H.E.	—	14·8	44·9	57·0	116·7
Total	—	14·8	499·3	666·4	1,180·5
Dudley—					
18-pdr. H.E.	—	—	35·8	1·4	37·2
60-pdr. S.	—	247·3	582·1	611·8	1,441·2
6-in. H.E.	—	77·8	250·4	3·3	331·5
6-in. Chemical ..	—	—	105·1	544·2	649·3
Total	—	325·1	973·4	1,160·7	2,459·2
Hackney Marshes—					
6-in. H.E.	—	236·6	418·1	380·5	1,035·2
6-in. Chemical ..	—	—	—	346·5	346·5
Total	—	236·6	418·1	727·0	1,381·7

APPENDIX II—*contd.*

	1915.	1916.	1917.	1918.	Total.
Lancaster—					
60-pdr. S.	—	139·0	252·2	198·3	589·5
6-in. H.E.	—	30·8	254·5	474·0	759·3
6-in. Chemical ..	—	—	—	234·6	234·6
8-in. H.E.	—	—	9·4	0·2	9·6
9·2-in. H.E.	—	69·2	204·0	174·8	448·0
Total	—	239·0	720·1	1,081·9	2,041·0
Leeds[1]—					
4·5-in. H.E.	37·3	105·2	1·5	—	144·0
6-in. H.E.	—	167·7	394·1	430·4	992·2
8-in. H.E.	—	—	8·6	5·2	13·8
9·2-in. H.E.	—	66·6	191·8	172·9	431·3
12-in. H.E.	—	—	0·1	6·5	6·6
15-in. H.E.	—	1·4	4·6	1·3	7·3
Total	37·3	340·9	600·7	616·3	1,595·2
Mile End (*Glasgow*)—					
18-pdr. H.E... ..	—	—	378·2	81·6	459·8
60-pdr. H.E... ..	—	136·1	197·3	346·2	679·6
6-in. H.E.	—	108·3	399·4	335·4	843·1
6-in. Chemical ..	—	—	—	25·7	25·7
Total	—	244·4	974·9	788·9	2,008·2
Nottingham—					
6-in. H.E.	—	134·9	433·5	115·9	684·3
9·2-in. H.E.	—	73·3	136·8	—	210·1
Total	—	208·2	570·3	115·9	894·4
Ponders End—					
6-in. H.E.	—	—	113·8	180·8	294·6
8-in. H.E.	—	—	126·5	173·2	299·7
12-in. H.E.	—	—	·7	—	·7
Total	—	—	241·0	354·0	595·0
Renfrew—					
60-pdr. S.	—	97·1	179·1	369·5	645·7
9·2-in. H.E.	—	—	36·9	27·4	64·3
12-in. H.E.	—	4·9	1·2	—	6·1
Total	—	102·0	217·2	396·9	716·1
Sheffield (*Hadfield*)—					
9·2-in. H.E.	—	119·0	167·1	3·1	289·2
Total	—	119·0	167·1	3·1	289·2

[1] Includes Armley, Newlay and Hunslet.

APPENDIX II—*contd.*

	1915.	1916.	1917.	1918.	Total.
Sheffield (*Firth*)—					
60-pdr. H.E.	—	355·7	618·3	701·9	1,675·9
60-pdr. Chemical ..	—	—	—	166·9	166·9
4·5-in. H.E.	—	—	411·3	239·2	650·5
4·5-in. Chemical ..	—	—	—	115·8	115·8
Total	—	355·7	1,029·6	1,223·8	2,609·1
Totals—					
18-pdr. H.E.	—	—	464·7	83·2	547·9
18-pdr. S.	—	—	454·4	609·4	1,063·8
4-in. H.E.	—	—	—	16·2	16·2
4·5-in. H.E.	37·3	105·2	583·8	535·9	1,262·2
4·5-in. Chemical ..	—	—	—	115·8	115·8
60-pdr. H.E.	—	491·8	815·6	1,048·1	2,355·5
60-pdr. S.	—	527·5	1,159·3	1,450·6	3,137·4
60-pdr. Chemical ..	—	—	—	166·9	166·9
6-in. How. H.E. ..	—	864·8	2,816·6	2,667·5	6,348·9
6-in. How. Chemical ..	—	—	105·1	1,470·8	1,575·9
8-in. H.E.	—	234·1	957·5	871·1	2,062·7
9·2-in. H.E.	—	328·1	736·6	378·2	1,442·9
12-in. H.E.	—	4·9	2·0	6·5	13·4
15-in. H.E.	—	1·4	4·6	1·3	7·3
Grand Total ..	37·3	2,557·8	8,100·2	9,421·5	20,116·8

APPENDIX III

(CHAPTER V.)

Output of Filled Shell from National Filling Factories.

[Figures in Thousands.]

	1915.	1916.	1917.	1918.	Total.
Banbury—					
18-pdr. Chemical ..	—	—	—	250·6	250·6
6-pdr. C.P.	—	—	—	225·6	225·6
60-pdr. H.E.	—	228·1	490·4	103·7	822·2
60-pdr. S.	—	—	—	608·6	608·6
4·5-in. Chemical ..	—	—	—	93·4	93·4
6-in. Gun S.	—	—	—	67·0	67·0
6-in. How. H.E. ..	—	25·6	848·2	189·1	1,062·9
6-in. Chemical ..	—	—	—	387·0	387·0
8-in. H.E.	—	5·3	—	10·9	16·2
9·2-in. How. H.E. ..	—	131·8	197·8	2·5	332·1
Total	—	390·8	1,536·4	1,938·4	3,865·6
Chilwell—					
60-pdr. H.E.	—	667·0	1,435·0	918·1	3,020·1
4·5-in. H.E.	—	45·0	—	—	45·0
6-in. Gun H.E. ..	—	—	27·2	227·7	254·9
6-in. How. H.E. ..	—	1,196·4	4,200·6	5,762·2	11,159·2
9·2-in. Gun H.E. ..	—	—	—	8·9	8·9
8-in. H.E.	—	541·2	1,433·0	952·8	2,927·0
9·2-in. How. H.E. ..	—	555·7	1,005·1	192·2	1,753·0
12-in. How. H.E. ..	—	43·1	67·1	52·3	162·5
15-in. H.E.	—	1·1	·5·9	5·1	12·1
Total	—	3,049·5	8,173·9	8,119·3	19,342·7
Chittening—					
6-in. How. Chemical..	—	—	—	86·4	86·4
Total	—	—	—	86·4	86·4
Devonport—					
18-pdr. S. completing foreign	47·6	1,963·1	1,046·3	—	3,057·0
Total	47·6	1,963·1	1,046·3	—	3,057·0

APPENDIX III—*contd.*

	1915.	1916.	1917.	1918.	Total.
Georgetown—					
18-pdr. H.E.	—	1,218·1	2,942·6	3,784·4	7,945·1
,, completing foreign	—	41·5	—	—	41·5
18-pdr. S.	—	1,130·2	2,004·3	1,958·5	5,093·0
13-pdr. (9-cwt.) H.E.	—	—	19·9	420·9	440·8
3-in. (20-cwt.) H.E. ..	—	—	—	114·8	114·8
18-pdr. H.E. A.A. ..	—	—	4·6	·3	4·9
60-pdr. S.	—	154·6	376·6	123·1	654·3
4·5-in. H.E.	—	220·1	1,607·8	1,070·5	2,898·4
4·5-in. S.	—	6·4	—	—	6·4
6-in. How. H.E. ..	—	32·0	538·6	1,469·8	2,040·4
9·2-in. H.E.	—	—	—	7·7	7·7
12-in. H.E.	—	—	24·8	21·1	45·9
Total	—	2,802·9	7,519·2	8,971·1	19,293·2
Gloucester—					
18-pdr. H.E.	—	195·2	2,024·9	1,089·7	3,309·8
,, completing foreign	—	1,022·1	181·2	—	1,203·3
18-pdr. S.	—	766·9	1,449·9	3,404·7	5,621·5
,, completing foreign	—	18·7	73·1	55·6	147·4
60-pdr. S.	—	17·6	—	—	17·6
Total	—	2,020·5	3,729·1	4,550·0	10,299·6[1]
Hayes—					
18-pdr. H.E.	—	—	1,390·1	881·5	2,271·6
,, completing foreign	10·6	1,888·5	806·4	—	2,705·5
18-pdr. S.	—	113·4	885·4	776·8	1,775·6
,, completing foreign	15·4	37·2	—	—	52·6
60-pdr. H.E.	—	73·5	13·1	—	86·6
4·7-in. H.E.	—	23·3	—	—	23·3
4·5-in. H.E.	—	1,245·9	1,777·6	1,831·9	4,855·4
6-in. Gun S.	—	—	—	37·8	37·8
6-in. How. H.E. ..	—	87·6	177·8	307·0	572·4
12-in. H.E.	—	—	·2	—	·2
Total	26·0	3,469·4	5,050·6	3,835·0	12,381·0
Hereford—					
18-pdr. Chemical ..	—	—	—	1·0	1·0
60-pdr. H.E.	—	—	—	291·2	291·2
6-in. How. H.E. ..	—	6·8	778·4	877·4	1,662·6
6-in. How. Chemical..	—	—	—	61·2	61·2
8-in. H.E.	—	—	368·6	839·1	1,207·7
9·2-in. How. H.E. ..	—	—	119·2	827·5	946·7
Total	—	6·8	1,266·2	2,897·4	4,170·4
Horley—					
18-pdr. S. completing foreign	—	3,158·5	1,578·6	—	4,737·1
Total	—	3,158·5	1,578·6	—	4,737·1

[1] Exclusive of 384, 269 4·5in. shell filled and assembled at Gloucester N.F.F.

Appendix III—*contd.*

	1915.	1916.	1917.	1918.	Total.
Leeds—					
18-pdr. H.E.	—	949·4	3,096·5	5,012·1	9,058·0
,, completing foreign	—	4·8	—	—	4·8
18-pdr. S.	—	321·7	—	—	321·7
,, completing foreign	—	10·6	—	—	10·6
60-pdr. H.E.	—	6·6	—	—	6·6
60-pdr. S.	—	2·0	142·9	39·5	184·4
4·5-in. H.E.	—	2,939·0	6,040·9	4,328·7	13,308·6
6-in. How. H.E. ..	—	277·2	362·7	1,035·1	1,675·0
Total	—	4,511·3	9,643·0	10,415·4	24,569·7
Liverpool—					
18-pdr. H.E.	—	418·7	2,539·2	1,118·6	4,076·5
,, completing foreign	—	1,092·4	257·1	—	1,349·5
18-pdr. S.	—	855·5	2,623·3	3,387·4	6,866·2
,, completing foreign	—	9·5	—	—	9·5
18-pdr. incendiary ..	—	—	—	39·0	39·0
60-pdr. H.E.	—	·2	12·7	373·1	386·0
60-pdr. S.	—	26·2	—	—	26·2
4·5-in. H.E.	—	89·2	6·5	—	95·7
4·5-in. S.	—	10·0	15·6	—	25·6
5-in. H.E.	—	—	125·6	—	125·6
6-in. How. H.E. ..	—	184·6	1,562·4	2,467·9	4,214·9
8-in. H.E.	—	—	61·2	64·2	125·4
Total	—	2,686·3	7,203·6	7,450·2	17,340·1
Morecambe—					
60-pdr. H.E.	—	—	117·9	—	117·9
6-in. How. H.E. ..	—	368·3	1,826·7	—	2,195·0
8-in. H.E.	—	17·7	291·0	—	308·7
9·2-in. How. H.E. ..	—	18·9	242·9	—	261·8
12-in. H.E.	—	6·3	3·4	—	9·7
Total	—	411·2	2,481·9	—	2,893·1
Watford Nos. 1 *and* 2, *and Greenford—*					
60-pdr. Chemical ..	—	—	580·9	63·8	644·7
4·5-in. Chemical ..	—	18·0	954·7	1,137·3	2,110·0
4·5-in. Smoke ..	—	—	118·5	349·2	467·7
6-in. How. Chemical..	—	—	49·8	774·4	824·2
Total	—	18·0	1,703·9	2,324·7	4,046·6

APPENDIX III—*contd.*

	1915.	1916.	1917.	1918.	Total.
Totals—					
18-pdr. H.E.	10·6	6,830·7	13,238·0	11,886·3	31,965·6
18-pdr. S.	63·0	8,385·3	9,660·9	9,583·0	27,692·2
18-pdr. Chemical ..	—	—	—	251·6	251·6
18-pdr. Incendiary ..	—	—	—	39·0	39·0
13-pdr. (9-cwt.) H.E.	—	—	19·9	420·9	440·8
3-in. (20-cwt.) H.E. ..	—	—	—	114·8	114·8
18-pdr. A.A. H.E. ..	—	—	4·6	·3	4·9
6-pdr. C.P.	—	—	—	225·6	225·6
60-pdr. H.E.	—	975·4	2,069·1	1,686·1	4,730·6
60-pdr. S.	—	200·4	519·5	771·2	1,491·1
60-pdr. Chemical ..	—	—	580·9	63·8	644·7
4·7-in. H.E.	—	23·3	—	—	23·3
4·5-in. H.E.	—	4,539·2	9,432·8	7,231·1	21,203·1
4·5-in. S.	—	16·4	15·6	—	32·0
4·5-in. Chemical ..	—	18·0	954·7	1,230·7	2,203·4
4·5-in. Smoke ..	—	—	118·5	349·2	467·7
5-in. H.E.	—	—	125·6	—	125·6
6-in. Gun H.E. ..	—	—	27·2	227·7	254·9
6-in. Gun S.	—	—	—	104·8	104·8
6-in. How. H.E. ..	—	2,178·5	10,295·4	12,108·5	24,582·4
6-in. How. Chemical..	—	—	49·8	1,309·0	1,358·8
9·2-in. Gun. H.E. ..	—	—	—	8·9	8·9
8-in. How. H.E. ..	—	564·2	2,153·8	1,867·0	4,585·0
9·2-in. How. H.E. ..	—	706·4	1,565·0	1,029·9	3,301·3
12-in. H.E.	—	49·4	95·5	73·4	218·3
15-in. H.E.	—	1·1	5·9	5·1	12·1
Grand Total ..	73·6	24,488·3	50,932·7	50,587·9	126,082·5[1]

[1] Exclusive of 384,269 4·5-in. shell filled and assembled at Gloucester N.F.F.

APPENDIX IV.

Chronological Schedule of the National Factories controlled by the Ministry of Munitions, June, 1915, to November, 1918.

Key to Abbreviations:

H.M.E.F. = H.M. Explosives Factory.
N.S.F. = National Shell Factory.
N.P.F. = National Projectile Factory.
N.O.F. = National Ordnance Factory.
N.F.F. = National Filling Factory.
T.W.F.F. = Trench Warfare Filling Factory.
G.C.F. = Government Cartridge Factory.
N.A.F. = National Aircraft Factory.

(*c*) After the date signifies date of construction or equipment as a national factory; (*n*) Signifies date of nationalisation of an existing trade factory. Where a factory was administered under an agency agreement the name of the firm which acted as agent is given. Figures marked * represent capital expenditure to 31 March, 1919.

Name and Address of Factory.	Class of Factory.	Date of Initiation.	Date of First Output.	Output.	Form of Administration.	Capital Expenditure to 31/3/18.*
						£
1. *Woolwich*, Royal Arsenal[1]	Royal Ordnance Factory.	*c* 1695 (*c*)	—	Making and repairing guns and carriages; making, filling and assembling shell and components; making small arms, ammunition, &c.	Direct Control ..	—
2. *Waltham Abbey*, Royal Gunpowder Factory[1]	Royal Ordnance Factory.	1787 (*n*)	—	Cordite, gunpowder, tetryl, guncotton and fuse powder.	Direct Control ..	—
3. *Enfield Lock*, Royal Small Arms Factory[1]	Royal Ordnance Factory.	1804 (*c*)	—	Rifles, machine guns, and small arms..	Direct Control ..	—
4. *Farnborough* [Hants][2]	Royal Aircraft Establishment.	1905 (*c*)	—	Aircraft and aircraft materials (mainly experimental work).	Direct Control ..	—
5. *Coleford* [Glos.][3]	H.M.E.F.	1913 (*c*)	—	Producing acetate of lime by wood distillation.	Direct Control ..	40,900
6. *Rainham* [Essex][4]	H.M.E.F.	Nov., 1914 (*c*)	Jan., 1915	Purifying crude T.N.T...	(*a*) Coley & Wilbraham; (*b*) Direct Control.	35,000
7. *Oldbury* [Worcs.]	H.M.E.F.	Jan., 1915 (*c*)	May, 1915	T.N.T.	Chance & Hunt ..	835,300*
8. *Queen's Ferry* [nr. Chester] ..	H.M.E.F.	May, 1915 (*c*)	Dec., 1915	Guncotton, T.N.T. and tetryl ..	Direct Control ..	3,430,300
9. *Bideford* [Devon][3]	H.M.E.F.	*c* May, 1915 (*c*)	—	Producing acetate of lime by wood distillation.	Direct Control ..	48,100
10. *Dundee*, Graham Street[3]	H.M.E.F.	*c* May, 1915 (*c*)	—	Producing acetate of lime by wood distillation.	Direct Control ..	19,100
11. *Leeds*, Armley Road[5]	N.S.F., N.P.F., N.O.F.	May, 1915 (*c*)	Sept., 1915	4·5-in. and 6-in. shell; repair and inspection of guns (1917–18).	Board of Management.	248,400

[1] Transferred from War Office, August, 1915. [2] Transferred from War Office, November, 1916. [3] Transferred from Office of Woods and Forests, October, 1915.
[4] Destroyed by fire, February, 1918. [5] Classed as N.P.F. 1916–17, N.O.F. 1917–18.

Appendix IV—*contd.*

Name and Address of Factory.	Class of Factory.	Date of Initiation.	Date of First Output.	Output.	Form of Administration.	Capital Expenditure to 31/3/18*
						£
12. *Keighley No.* 1, Dalton Lane	N.S.F.	May, 1915 (*c*)	Autumn, 1915	18-pdr., 3·7-in. and 6-pdr. (A.A.) shell	Board of Management.	51,200
13. *Birmingham*, Midland Works, Washwood Heath.	N.S.F.	June, 1915 (*c*)	Feb., 1916	Making and completing 18-pdr. and 4·5-in. shell.	Board of Management.	187,600
14. *Bradford*, Valley Road	N.S.F.	June, 1915 (*c*)	Nov., 1915	4·5-in. shell, fuses, gaines, &c., completing 4·5-in. shell.	Board of Management.	56,700
15. *Bristol*, Victoria Road	N.S.F.	June, 1915 (*c*)	Early, 1916	Completing and rectifying 18-pdr. shell	Board of Management.	20,000
16. *Derby*, Peel Foundry	N.S.F.	June, 1915 (*c*)	Dec., 1915	4·5-in. and 4·7-in. shell; 60-pdr. and 6-in. shell heads; aero-engine cylinders.	Board of Management.	75,000
17. *Huddersfield*, Fitzwilliam Street	N.S.F.	June, 1915 (*c*)	Nov., 1915	18-pdr. shell and shell heads	Board of Management.	31,500
18. *Dublin*, Parkgate Street	N.S.F.	June, 1915 (*c*)	March, 1916	18-pdr. shell	Board of Management.	119,600[1]
19. *Liverpool*, Cunard Co., Rimrose Road	N.S.F.	June, 1915 (*c*)	—	8-in., 6-in. and 4·5-in. shell	Board of Management.	16,600
20. *Liverpool*, North Haymarket	N.S.F.	June, 1915 (*c*)	—	18-pdr., 4·5-in. and 6-in. shell	Board of Management.	131,000
21. *Liverpool*, Lambeth Road Tramway Depot.	N.S.F.	June, 1915 (*c*)	July, 1915	18-pdr. shell; completing and rectifying 18-pdr., 15-pdr. 2·75-in., 4·5-in. and 60-pdr.	Board of Management.	22,000
22. *Nottingham*, Spring Close Works, Old Lenton.	N.S.F.	June, 1915 (*c*)	Late 1915	13-pdr., 18-pdr. and 2·75-in. shell; completing 18-pdr.	Board of Management.	25,800
23. *Rotherham*, Brinsworth Iron Works and Rotherham Iron Works.	N.S.F.	June, 1915 (*c*)	Nov., 1915	4·5-in. shell	Board of Management.	53,000
24. *Dundee*, 51–63, Mains Road	N.S.F.	June, 1915 (*c*)	Sept., 1915	18-pdr. and 2·75-in. shell; forgings; burster containers.	Board of Management.	34,000
25. *Ebbw Vale* [Mon.][2]	N.S.F.	June, 1915 (*c*)	Aug., 1915	18-pdr. and 60-pdr. shell	Board of Management.	32,200
26. *Cardiff*, Ferry Road, Grangetown	N.S.F.	June, 1915 (*c*)	Late 1915	18-pdr. shell, 60-pdr. shell heads, 6-in. proof shot.	Board of Management.	28,500
27. *Swansea*, Messrs. Baldwin's Works, Landore.	N.S.F.	June, 1915 (*c*)	Late 1915	18-pdr. and 4·5-in. shell	Board of Management.	40,500
28. *Wrexham*, Corporation Electric Works	N.S.F.	July, 1915 (*c*)	Spring, 1916	Making and completing 18-pdr. and 13-pdr. shell.	Board of Management.	9,000
29. *Uskside*, Uskside National Works, Newport [Mon.]	N.S.F.	July, 1915 (*n*)	—[3]	18-pdr., 4·5-in. and 60-pdr. shell; proof shot and gun-carriage forgings, &c.	Board of Management.	61,900
30. *Gadbrook* [nr. Northwich, Cheshire]	H.M.E.F.	July, 1915 (*c*)	Feb., 1916	Purifying crude T.N.T.	Brunner Mond	195,000[4]

31. *Gretna* [nr. Carlisle]	H.M.E.F.	July, 1915 (*c*)	June, 1916	Cordite R..D.B.	Direct Control ..	9,295,000*
32. *Hackney Wick*, Wallis Rd. [London, N.E.]	H.M.E.F.	July, 1915 (*n*)	July, 1915	T.N.T.	Direct Control ..	66,200*
33. *Penrhyn Deudraeth* [N. Wales] ..	H.M.E.F.	July, 1915 (*n*)	Jan., 1916	T.N.T.	Direct Control ..	83,000*
34. *Liverpool*, Aintree	N.F.F.	July, 1915 (*c*)	June, 1916	Filling shell up to 8-in.; filling and assembling components.	Board of Management.	725,400
35. *Coventry*, Foleshill	N.F.F.	July, 1915 (*c*)	March, 1916	Filling fuses, gaines and other components.	White & Poppé ..	813,400
36. *Watford*	H.M.E.F.	Aug., 1915 (*c*)	Dec., 1915	Ammonal, amatol, smoke powder, &c.; experimental work.	Direct Control ..	106,800
37. *Barnsley* (*No.* 1), Dominion Works, Johnson Street.	N.S.F.	Aug., 1915 (*c*)	Jan., 1916	4·5-in. shell	Board of Management.	51,000
38. *Grimsby*, Victoria Street	N.S.F.	Aug., 1915 (*c*)	Dec., 1915	4·5-in. and 6-in. shell	Board of Management.	28,700
39. *Leeds*, Newlay[5]	N.S.F., N.P.F., N.O.F.	Aug., 1915 (*c*)	April, 1916	9·2-in. and 15-in. shell	Board of Management.	230,600
40. *Chester*, Tramway Depot	N.S.F.	Aug., 1915 (*c*)	—	18-pdr. and 2·75-in. shell	Board of Management.	2,400
41. *Birtley* [Co. Durham]	N.P.F.	Aug., 1915 (*c*)	July, 1916	4-in., 4·5-in., 60-pdr., 6-in., 8-in. shell; proof shot.	Belgian Government	892,800
42. *Dudley*, Waddam's Pool	N.P.F.	Aug., 1915 (*c*)	Early 1916	18-pdr., 60-pdr. and 6-in. shell; gun repair (1917), aero-engine work (1918)	Bean & Son ..	788,000
43. *Glasgow*, Mossend	N.P.F.	Aug., 1915 (*c*)	Late 1916	Shell forgings	Beardmore, Ltd. ..	1,107,600
44. *Glasgow*, Grant's Mill, Mile End[6] ..	N.P.F.	Aug., 1915 (*c*)	March, 1916	18-pdr., 60-pdr. and 6-in. shell ..	Beardmore, Ltd. ..	
45. *Glasgow*, Cardonald, Paisley[7] ..	N.P.F.	Aug., 1915 (*c*)	March, 1916	18-pdr., 6-in. and 8-in. shell; gun repair (1917).	Beardmore, Ltd. ..	
46. *Lancaster*	N.P.F.	Aug., 1915 (*c*)	March, 1916	60-pdr., 6-in., 8-in. and 9·2-in. shell; gun repair and trench warfare work (1917).	Vickers, Ltd. ..	1,580,200
47. *Nottingham*, King's Meadow Road[8] ..	N.P.F., N.O.F. ..	Aug., 1915 (*c*)	March, 1916	6-in. and 9·2-in. shell; making and repairing 18-pdr. guns (1917–18).	Cammell, Laird ..	796,500
48. *Chilwell*, Long Eaton [Notts.] ..	N.F.F.	Aug., 1915 (*c*)	Jan., 1916	Filling shell (4·5-in. to 15-in.)	Direct Control ..	2,712,100
49. *Perivale*, Willesden Lane [London, N.W.]	N.F.F.	Aug., 1915 (*c*)	Dec., 1915.	Filling shell components; experimental work.	(*a*) Metropolitan Munitions Committee (*b*) Direct Control	522,800
50. *Morecambe*, White Lund [Lancs.] ..	N.F.F.	Aug., 1915 (*c*)	Summer, 1916	Filling 60-pdr., 6-in., 8-in., 9·2-in. and 12-in. shell.	Vickers, Ltd. ..	199,900
51. *Southwark*, Sumner St. [London, S.E.].[9]	N.F.F.	Aug., 1915 (*c*)	Sept., 1915	Filling shell components; inspecting protective clothing (1918).	Direct Control ..	41,100
52. *Cathcart*, Holm Foundry [nr. Glasgow.][10]	N.P.F.	Sept., 1915 (*c*)	April, 1916	8-in. shell; aeronautical work (1917–18).	G. & J. Weir ..	36,100
53. *Sheffield*, Tinsley [nr. Sheffield] and Templeborough [nr. Rotherham.]	N.P.F.	Sept., 1915 (*c*)	Jan., 1916	Shell forgings; 4·5-in. and 60-pdr. shell.	T. Firth & Sons ..	661,800

[1] Includes expenditure on Dublin 9·2-in. and Fuse Factories (Nos. 93 & 105). [2] Closed down July, 1916. [3] Already in operation when taken over. [4] Expenditure to July, 1918. [5] Classed as an N.P.F. 1916–17; N.O.F. 1917–18. [6] Also known as Bridgeton. [7] Also known as Craigton. [8] Classed as N.O.F. 1917–18. [9] Transferred to Anti-Gas authorities in 1918; later used for storing the Ministry archives. [10] Transferred to Controller of Aeronautical Supplies May, 1917.

APPENDIX IV—*contd.*

Name and Address of Factory.	Class of Factory.	Date of Initiation.	Date of First Output.	Output.	Form of Administration.	Capital Expenditure to 31/3/18.*
						£
54. *Sheffield*, East Hecla Works. ..	N.P.F., N.O.F. ..	Sept., 1915 (*c*)	March, 1916	9·2-in. shell; 60-pdr. guns and gun repairs (1917–18).	Hadfield Ltd. ..	487,800
55. *Bury*, Corporation Tramway Depot	N.S.F.	Sept., 1915 (*c*)	Summer, 1916	18-pdr. and 4·5-in. shell; rectifying shell.	Board of Management.	11,700
56. *Carlisle*, Drill Hall, Strand Rd. ..	N.S.F.	Sept., 1915 (*c*)	Early, 1916	18-pdr. shell; rectifying proof shot ..	Board of Management.	12,800
57. *Liverpool*, Edge Lane	N.S.F.	Sept., 1915 (*c*)	Feb., 1916	4·5-in. and 6-in. shell forgings; 4·5-in. cartridge cases.	Board of Management.	96,000
58. *Llanelly*, Burry Extension Works ..	N.S.F.	Sept., 1915 (*c*)	Feb., 1916	6·in. shell.	Board of Management.	171,500[1]
59. *Abbey Wood* [London, S.E.] ..	N.F.F.	Sept., 1915 (*c*)	Jan., 1916	Filling and assembling shell components.	King's Norton Metal Co.	116,400
60. *Gloucester*, Quedgeley	N.F.F.	Sept., 1915 (*c*)	March, 1916	Filling 18-pdr., 4·5 in. and 60-pdr. shell, cartridges and components.	Board of Management.	410,400
61. *Georgetown* [Paisley]	N.F.F.	Sept., 1915 (*c*)	Jan., 1916	Filling shell (13-pdr. to 12-in.), cartridges, components, trench mortar bombs.	Board of Management.	1,368,400
62. *Hayes* [Middlesex]	N.F.F.	Sept., 1915 (*c*)	Oct., 1915	Filling shell (18-pdr. to 12-in.), cartridges, components.	Direct Control ..	899,000
63. *Leeds*, Barnbow[2]	N.F.F.	Sept., 1915 (*c*)	Dec., 1915	Filling shell (18-pdr. to 6-in.), cartridges, components.	Board of Management.	813,500
64. *Cardonald*, Govan [Glasgow] ..	N.F.F.	Sept., 1915 (*c*)	Jan., 1916	Filling minor shell components. ..	Nobel's Explosives Co.	63,500
65. *Watford* (*No.* 1), Balmoral Road ..	T.W.F.F.	Sept., 1915 (*c*)	Oct., 1915	Filling and assembling trench warfare bombs; filling chemical shell exploders.	Direct Control ..	40,306
66. *Birmingham*, Great Tindal Street	National Gauge Factory.	Sept., 1915 (*n*)	—[3]	Gauges, small tools, &c.	Chatwin, Ltd. ..	2,900*
67. *Renfrew*, Ypres Factory	N.P.F.	Sept., 1915 (*c*)	Summer, 1916	9·2-in. and 12-in. forgings and shell ..	Babcock & Wilcox	165,900
68. *Trafford Park* [Barton, Manchester]	H.M.E.F. ..	Oct., 1915 (*c*)	July, 1916	Refining toluol	Hardman & Holden	37,400*
69. *West Gorton* [Manchester] ..	H.M.E.F. ..	Oct., 1915 (*n*)	—[3]	Synthetic phenol and T.N.T.	Direct Control ..	304,400*
70. *College Park* [Willesden, N.W.][4] ..	N.S.F., N.P.F. ..	Oct., 1915 (*n*)	—[3]	Shell components	(*a*) Metropolitan Munition Committee; (*b*) Direct Control.	4,000
71. *Carnarvon*, Vulcan Factory	N.S.F.	Oct., 1915 (*c*)	†	13-pdr. and 18-pdr. shell	Board of Management.	2,800
72. *Rochdale*, Mellor Street	N.S.F.	Oct., 1915 (*c*)	July, 1916	6-in shell	Board of Management.	19,600

73. *Hackney Marshes* [London, N.E.] ..	N.P.F.	Oct., 1915 (*c*)	Feb., 1916	6·in. shell and proof shot	(*a*) Dick Kerr; (*b*) Direct Control	652,600
74. *Newport*, Maesglas and Tyne Engine Works.	N.S.F.	*c*Oct., 1915 (*c*)	June, 1916	60-pdr. shell; 4·5-in. and 9·2-in. nose bushes.	Board of Management.	112,400
75. *Portmadoc*, Boston Lodge Works ..	N.S.F.	*c*Oct., 1915 (*c*)	—	13-pdr. and 18-pdr. shell . ..	Board of Management.	3,700
76. *Langwith* [nr. Mansfield, Notts.] ..	H.M.E.F.	Nov., 1915 (*c*)	June, 1917	Ammonium perchlorate . ..	Direct Control ..	717,400*
77. *Croydon*, Gloucester Road	National Gauge Factory.	Nov., 1915 (*n*)	—[3]	Gauges	Vidal Engineering Co.	14,800*
78. *Workington*, Stanley Street ..	N.S.F.	Nov., 1915 (*c*)	Aug., 1916	18-pdr. shell; base plates	Board of Management.	12,700
79. *Renfrew*, Aisne Factory	N.P.F.	Nov., 1915 (*c*)	May, 1916	60-pdr. shell	Babcock & Wilcox	114,600
80. *Liverpool*, Clyde Street, Bootle ..	N.S.F.	Nov., 1915 (*c*)	—	Gauges	Board of Management.	6,300
81. *Hartlepool*, Central Marine Engine Works[5]	N.S.F.	Dec., 1915 (*c*)	Autumn, 1916	8-in. shell	Board of Management.	48,500
82. *Rawtenstall and Bacup*, Irwell Mill, Bacup.	N.S.F.	Dec., 1915 (*c*)	Summer, 1916	4·5-in. shell.	Board of Management.	7,400
83. *Banbury* [Oxon]	N.F.F.	Dec., 1915 (*c*)	April, 1916	Filling shell (6-pdr. to 9·2-in.), H.2 Mines (1917-18).	Direct Control ..	174,000
84. *Sutton Oak* [St. Helen's, Lancs.] ..	H.M.E.F.	Jan., 1916(*n*)	—[3]	Synthetic Phenol; chemicals (1918).	Direct Control ..	100,700
85. *Denaby* [nr. Rotherham]	T.W.F.F.	Jan., 1916 (*n*)	—[3]	Filling 3-in. Stokes bombs; disassembling 3·7-in. bombs (1917).	British Westfalite Co.	14,700
86. *Erith*, Crayfordness, Slades Green [Kent].	T.W.F.F.	Jan., 1916 (*n*)	—[3]	Filling 2-in. and 6-in. trench mortar bombs.	Direct Control ..	42,000
87. *Fulham*, Stevenage Road [London, S.W.]	T.W.F.F.	Feb., 1916(*n*)	—[3]	Filling grenades, Stokes bombs and components; pyrotechnic work, &c.	Direct Control ..	19,700
88. *Watford* (*No.* 2), Bushey Mill Lane..	T.W.F.F.	Feb., 1916 (*c*)	May, 1916	Filling bombs, grenades, &c., filling and assembling aerial bombs and trench mortar fuses; assembling chemical shell.	Direct Control	99,000
89. *Victoria* [Winsford, Northwich] ..	H.M.E.F.	Feb., 1916 (*c*)	Aug., 1916	Calcium nitrate tetrahydrate ..	(*a*) Salt Union (*b*) Direct Control.	608,300
90. *Ellesmere Port* [Cheshire]	H.M.E.F.	March, 1916(*c*)	May, 1917	Synthetic phenol: chemicals (1918)	Direct Control ..	160,800*
91. *Litherland* [Liverpool]	H.M.E.F. ..	March, 1916(*n*)	—[3]	T.N.T.	Direct Control ..	185,000*
92. *King's Lynn* [Norfolk]	H.M.E.F.	March, 1916(*n*)	—[3]	Acetone	Direct Control ..	4,300*
93. *Dublin*, Parkgate Street	N.S.F.	March, 1916(*c*)	April, 1917	9·2-in. shell	Board of Management.	—[6]
94. *Manchester*, Hyde Road	N.S.F.	March, 1916 (*c*)	Summer, 1916	4·5-in. shell	Board of Management.	16,500
95. *Leeds*, Hunslet[7]	N.S.F., N.P.F., N.O.F.	Early 1916 (*c*)	Aug., 1916	9·2-in. and 15-in. shell; making and repairing guns (1917–18).	Board of Management.	274,400
96. *Leeds*, Armley Road, Wellington Street, and Sweet Street.[7]	National Fuse Factory.	Early 1916 (*c*)	—	Shell components	Board of Management.	26,400

[1] Includes Llanelly Rectification Factory (No. 115). [2] Also known as Crossgates. [3] Already in operation when nationalised.
[4] Classed as an N.P.F. in 1918. [5] Transferred to Admiralty, December, 1917. [6] Expenditure included with Dublin 18-pdr. Shell Factory (No. 18).
[7] Classed as N.P.F. 1916–17; N.O.F. 1917–18.

Appendix IV—*contd.*

Name and Address of Factory.	Class of Factory.	Date of Initiation.	Date of First Output.	Output.	Form of Administration.	Capital Expenditure to 31/3/18.*
						£
97. *Cork*, North Main Street	N.S.F.	Early 1916 (*c*)	Feb., 1917	4·5-in. shell	Board of Management	14,000
98. *Dagenham Dock* [Essex]	National Cartridge and Box Repair Factory.	Early 1916 (*c*)	Early 1916	Repairing cartridge cases and ammunition boxes.	Direct Control	124,300
99. *Southampton*, Woolston	Government Rolling Mills.	April, 1916 (*c*)	Feb., 1917	Brass and cupro-nickel strips and cups	Mr. G. H. Robinson	1,089,900
100. *Blackheath* [Staffs.]	G.C.F.	*c* April, 1916 (*c*)	Dec., 1916	Small arms ammunition	Birmingham Metal & Munitions Co.	392,000
101. *Blackpole* [Worcs.]	G.C.F.	*c* April, 1916 (*c*)	Early, 1917	Small arms ammunition	King's Norton Metal Co.	289,800
102. *Craigleith* [Edinburgh]	H.M.E.F.	April, 1916 (*c*)	Feb., 1917	T.N.T.	Lothian Chemical Co.	67,900*
103. *Gateshead*, Coulthard's Lane	National Tool Factory.	May, 1916 (*c*)	Aug., 1916	Spade-cutters	Direct Control	18,800
104. *Phœnix Factory* [Gray's Inn Road, London, W.C.]	National Fuse Rectification Factory.	May, 1916 (*n*)	—[1]	Rectifying and repairing fuses	William Cubitt, Ltd.	22,500
105. *Dublin*, Parkgate Street	National Fuse Factory.	May, 1916 (*c*)	March, 1917	Fuses; aeroplane bolts (1918)	Board of Management.	—[2]
106. *Selby*, Barlby Road [Yorks.]	T.W.F.F.	June, 1916 (*n*)	—	Hydrogen and hydrogenated oils; charging chemical shell.	Ardol, Ltd.	—
106.*a Colnbrook* [Mddx.]	H.M.E.F.	June, 1916 (*n*)	—[1]	Guncotton	Direct Control	—
107. *Walthamstow*, Black Horse Lane	T.W.F.F.	June, 1916 (*n*)	—[1]	Charging lachrymatory grenades, shells, &c.; head filling lethal shell.	(*a*) Baird & Tatlock (*b*) Direct Control.	9,900*
108. *Hereford*	N.F.F.	June, 1916 (*n*)	Nov., 1916	Filling shell (18-pdr. to 9·2-in.); charging gas shell (1918).	Direct Control	1,281,300
109. *Ailsa Craig* [Strand-on-Green, Chiswick.	N.S.F., N.P.F.	July, 1916 (*n*)	—[1]	4·5-in. shell	(*a*) Metropolitan Munitions Committee (*b*) Direct Control.	26,400
110. *Darlington*, N.E.R. Co.'s Works	N.P.F.	July, 1916 (*n*)	—[1]	18-pdr. and 6-in. shell; naval practice shot; repairing primers.	N.E.R. Co.	106,400
111. *Edmonton*, Angel Road[3]	G.C.F.	Aug., 1916 (*c*)	May, 1917	Small arms ammunition; aero-engine repair (1918).	Eley Bros.	284,200
112. *Greenford* [Middlesex]	Chemical Shell Assembling Station.	Aug., 1916 (*c*)	Jan., 1917	Assembling lethal shell	Direct Control	109,900
113. *Woolwich*, Upper Market Street	National Gauge Factory.	Aug., 1916 (*n*)	—[1]	Gauges	Pitter's Ventilating & Engineering Co.	34,500*
114. *Avonmouth* [Glos.][4]	H.M.E.F.	Sept., 1916 (*c*)	July, 1918	Mustard gas	Direct Control	1,578,200
115. *Llanelly*	N.S.F.	Sept., 1916 (*c*)	—	Rectifying 18-pdr. and 6-in. shell	Board of Management.	—[5]

116. *Luton*, Chaul End [Beds].	N.F.F.	Autumn, 1916 (c)	Summer, 1917	Filling and converting fuses	George Kent, Ltd.	—
117. *Beddington* [Croydon]	Box Repair Factory	Nov., 1916 (c)	Early 1917	Repairing bomb and grenade boxes ..	Direct Control ..	7,200
118. *Waterford*	National Cartridge Factory. ..	Nov., 1916 (c)	Aug., 1917	Cartridge cases	Board of Management.	82,300
119. *Swindon*, Stratton Works	H.M.E.F.	Dec., 1916 (c)	Sept., 1917	Ammonium nitrate	Direct Control ..	927,600
120. *Galway*	N.S.F.	c Dec., 1916 (c)	Spring, 1917	18-pdr. shell	Board of Management.	4,000
121. *Trafford Park*, Manchester	Steel Billet Breaking Factory.	1916 (c)	—	Breaking steel billets to shell lengths..	Direct Control ..	142,200
122. *Woolwich*, Trinity Street	National Box Factory.	1916 (c)	Late 1916	Making and repairing ammunition boxes	W. Watt Torrance & Co.	3,200*
123. *Deptford* (*No.* 1), Pier Wharf [London, S.E.]	National Box Factory.	1916 (c)	Late 1916	Making and repairing tin boxes ..	Direct Control ..	5,400*
124. *Stamford Hill*, L.C.C. Stores Depot [London, N.]	Anti-Gas Factory	1916 (c)	Feb., 1917	Granules	Direct Control ..	—
125. *Willesden*, Park Royal [London, N.W.]	National Box Factory.	Jan., 1917 (n)	—	Making and repairing ammunition boxes	Direct Control ..	28,000*
126. *Pembrey* [Carmarthen]	H.M.E.F.	Jan., 1917 (n)	—[1]	T.N.T., tetryl, and propellants ..	Nobel's Explosives Co.	2,850,600*
127. *Pembrey*, Burry Port [Carmarthen]	N.F.F.	Jan., 1917 (n)	—[1]	Filling 4·5-in., 6-in., 8-in. shell; breaking down shell, &c. (1917–18).	Explosives Loading Co.	102,300
128. *Pimlico*, Gatliff Road [London, S.W.]	National Gauge Factory.	Jan., 1917 (n)	—[1]	Gauges	Wolseley Motor Co.	22,000
129. *Bradley* [Yorks.]	H.M.E.F.	Jan., 1917 (c)	—	Picric acid	Major L. B. Holliday	369,500*
130. *Greetland* [nr. Halifax]	H.M.E.F.	Jan., 1917 (c)	Aug., 1917	Picric acid	Sharp & Mallett ..	183,600*
131. *Lytham* [Lancs.]	H.M.E.F.	Jan., 1917 (c)	July, 1917	Picric acid	(a) Mr. Lance Blythe (b) Direct Control	166,800*
132. *Irvine* [Ayrshire]	H.M.E.F.	Jan., 1917 (c)	Feb., 1918	Nitrocellulose powder	Nobel's Explosives Co.	953,200*
133. *Cowley* [nr. Oxford]..	Mine Sinker Assembly Station.	March, 1917 (n)	Aug., 1917	Assembling naval mine sinkers ..	W.R.M. Motors, Ltd.	21,600
134. *Ponders End* [Middlesex]	N.P.F.	March, 1917 (n)	—[1]	6-in., 8-in., 12-in. shell; 6-pdr. guns; repairing guns.	Direct Control ..	812,200*
135. *Aberdeen*, Spring Garden Iron Works	N.S.F.	March, 1917 (n)	—[1]	Completing 6-in. shell	Board of Management.	600
136. *Longparish* [nr. Andover]	H.M.E.F.	Early 1917 (n)	—[1]	Producing acetate of lime by wood distillation.	Kynoch, Ltd. ..	86,800*
137. *Tipton* [Staffs.]	National Components Factory.	Early 1917 (c)	—	Gun ammunition components.. ..	Bean & Son ..	—
138. *Newport*, Alexandra Dock [Mon.] ..	National Cartridge & Box Repair Factory.	Early 1917 (c)	—	Repairing cartridge cases and ammunition boxes.	Direct Control ..	314,000
139. *Erith*, Cory's Wharf, Belvedere [Kent]	Non-returnable Box Depot.	c April, 1917 (c)	April, 1917	Repairing and converting non-returnable boxes.	Direct Control ..	—
140. *Willesden*, Park Royal [London, N.W.]	Non-returnable Box Depot.	c April, 1917 (c)	April, 1917	Repairing and converting non-returnable boxes.	Direct Control ..	2,20

[1] Already in operation when nationalised. [2] Expenditure included with Dublin 18-pdr. Shell Factory (No. 18). [3] Transferred to Air Board, early 1918.
[4] Original plans for picric acid production abandoned early 1918. [5] Expenditure included with Llanelly Shell Manufacture Factory (No. 58).

APPENDIX IV—*contd.*

Name and Address of Factory.	Class of Factory.	Date of Initiation.	Date of First Output.	Output.	Form of Administration.	Capital Expenditure to 31/3/18*
						£
141. *Kilburn,* Fairfax Yard [London, N.W.]	National Gauge Factory.	May, 1917 (*c*)	—	Gauges	Direct Control ..	2,100*
142. *Rotherhithe,* Plough Road [London, S.E.]	National Sawmill..	July, 1917 (*n*)	—	Sawing timber	Priddy & Hale ..	11,500
143. *Glasgow,* 45, Milton Street, Partick..	National Sawmill..	July, 1917 (*n*)	—	Sawing timber	A. McDougall's Timber Co.	9,400
144. *Coundon* [nr. Coventry]	National S.A.A. Factory.	July, 1917 (*c*)	Sept., 1917	Special small arms ammunition ..	Direct Control ..	12,600*
145. *Bucknall,* Hanley [Staffs.]	Cylinder Depot ..	July, 1917 (*n*)	—[1]	Evacuating and refilling cylinders with chemicals.	Direct Control ..	11,500*
146. *Bury,* Calrow Mill						
147. *Charlesworth,* Lee Valley Mill ..						
148. *Greenfield* [Yorks.]						
149. *Hadfield,* Waterside Mill						
150. *Oldham*	H.M. Cotton Waste Mills.	Aug., 1917 (*n*)	—[1]	Cotton waste	(*a*) British & Foreign Supply Association; (*b*) Direct Control.	455,400*
151. *Rawtenstall,* Cloughfold, Constablelee & Holme Mills.						
152. *Whaley Bridge,* Hall's Mill						
153. *Woodley,* Arden Mill						
154. *Glasgow,* Whiteinch	National Sawmill	Sept., 1917 (*n*)	—	Sawing timber	J. Smellie & Co. ..	—
155. *Kilmarnock,* Bonington Road ..	National Sawmill..	Sept., 1917 (*n*)	—	Sawing timber	Brownlie & Co. ..	1,300
156. *Chelmsford* [Essex]	National Ball Bearing Factory.	Sept., 1917 (*n*)	—[1]	Ball bearings	Hoffman Manufacturing Co.	—
157. *Waddon* [Croydon]	N.A.F.	Sept., 1917 (*c*)	March, 1918	Aeroplanes and C.C. interrupter gears	Holland & Hannen & Cubitt.	778,300*
158. *Castleford* [Leeds]	National Box Factory.	Autumn 1917	by Oct., 1917	Making and repairing ammunition boxes.	Direct Control ..	2,500*
159. *Leeds* [Wellington Street]	National Box Factory.	Autumn 1917	by Oct., 1917	Making and repairing ammunition boxes.	J. H. Abrahams, Ltd.	2,300*
160. *Letchworth*	National Box Factory.	Autumn 1917	by Oct., 1917	Making and repairing ammunition boxes.	Co-partnership Co.	2,800*
161. *Liverpool,* Brasenose Road, Bootle	National Box Factory.	Autumn 1917	by Oct., 1917	Making and repairing ammunition boxes.	Direct Control ..	3,000*
162. *Paisley,* Caledonia Sawmills ..	National Box Factory.	Autumn 1917	by Oct., 1917	Making and repairing ammunition boxes.	Direct Control ..	1,700*
163. *Burton-on-Trent*	Machine-Gun Factory.	Oct., 1917 (*c*)	Jan., 1919	Repairing machine guns	Direct Control ..	892,400*
164. *Aintree* [Liverpool]	N.A.F.	Oct., 1917 (*c*)	June, 1918	Aeroplanes	(*a*) Cunard Ltd. (*b*) Direct Control.	692,900*

165. *Heaton Chapel* [Manchester]	N.A.F.	Oct., 1917 (*c*)	April, 1918	Aeroplanes	Crossley, Ltd. ..	544,500*
166. *Hayes* [Middlesex]	Aero-Engine Factory.	Oct., 1917 (*n*)	—[1]	Aero-engine parts	(*a*) Mitchell Shaw (*b*) Direct Control	211,346
167. *Inverness*, The Sawmills	National Sawmill	Oct., 1917 (*n*)	—	Sawing timber	J. Walker & Co.	2,500
168. *Elgin*, Morayshire Sawmills ..	National Sawmill	Oct., 1917 (*n*)	—	Sawing timber	A. Watson & Co.	6,400*
169. *Barnsley* (*No.* 2), Hope Works, Sackville Street.	N.S.F.	Oct., 1917 (*c*)	—	4·5-in. shell	Board of Management.	14,500
170. *Keighley* (*No.* 2), Dalton Lane ..	N.S.F.	Oct., 1917 (*c*)	by Sept., 1918	18-pdr. shell castings	Board of Management.	—
171. *Southampton*, Northam	National Sawmill	Nov., 1917 (*n*)	—	Sawing timber	Driver & Co. ..	6,200
172. *Poole*, Hamworthy [Dorset] ..	National Sawmill	Nov., 1917 (*n*)	—	Sawing timber	J. T. Sydenham & Co.	4,600
173. *Gloucester*, Bristol Road	National Sawmill	Nov., 1917 (*n*)	—	Sawing timber	J. Griggs & Co. ..	7,300
174. *Dumfries*, Leafield	National Sawmill	Nov., 1917 (*n*)	—	Sawing timber	—	—
175. *Warrington*, Walton Lay Bye ..	National Sawmill	Nov., 1917 (*n*)	—	Sawing timber	R. A. Naylor, Ltd.	12,000*
176. *Luton*, Dunstable Road	National Sawmill	Nov., 1917 (*n*)	—	Sawing timber	H. Brown & Sons	7,000
177. *Chittening*	N.F.F.	Nov., 1917 (*c*)	June, 1918	Charging and assembling 6-in. chemical shell.	(*a*) Nobel's Explosives Co. (*b*) Direct Control.	57,900*
178. *Gainsborough*	N.F.F.	Nov., 1917 (*c*)	Feb., 1918	Filling mine sinkers	Direct Control ..	52,000
179. *New Basford* [Nottingham] ..	N.O.F.	Dec., 1917 (*c*)	May, 1918	1½-pdr. automatic gun	Coventry Ordnance Works	199,000*
180. *Rawtenstall and Bacup*, Height Barn Mill, Bacup.	N.S.F.	Late 1917 (*c*)	Early 1918	Rectifying 18-pdr. and 4·5-in. shell and 6-in. shell forgings.	Board of Management.	19,500
181. *Blyth* [Northumberland]	Salvage Depot ..	Late 1917 (*c*)	—	Storing and sorting salvage	Direct Control ..	5,900*
182. *Immingham* [Yorks]	Salvage Depot ..	Late 1917 (*c*)	—	Storing and sorting salvage	Direct Control ..	3,800*
183. *Manchester*, Trafford Park	Salvage Depot ..	Late 1917 (*c*)	—	Storing and sorting salvage from overseas.	Direct Control ..	9,200*
184. *Renfrew*	Salvage Depot ..	Late 1917 (*c*)	—	Storing and sorting salvage	Direct Control ..	5,500*
185. *Ridham* [Kent]	Salvage Depot ..	Late 1917 (*c*)	—	Storing and sorting salvage	Direct Control ..	64,200*
186. *Westminster*, 14, Palmer Street ..	Small Tools Factory.	1917 (*n*)	—	Small tools	Coats Machine Tool Co.	8,300
187. *Glasgow*, Salamanca Street, Parkhead.	National Box Factory.	1917	—	Making and repairing tin boxes ..	Direct Control ..	—
188. *Deptford* (*No.* 2), Kent Wharf [London, S.E.].	National Box Factory.	1917–18	—	Making and repairing tin boxes ..	Direct Control ..	—
189. *Sheffield*, 50, Porter Street	Manufacturing Warehouse	1917–18	—	Cupro-nickel strip; brass discs ..	Direct Control ..	731*
190. *Merthyr Tydfil*, Cyfarthfa	Rolling Mills & Blast Furnaces.	1917–18	—	Basic pig iron; rolling 18-pdr. shell steel bars.	Crawshay Bros. ..	78,300
191. *Swindon*, G.W.R. Co.'s Works ..	Timber Drying Kiln	1917–18	July, 1918	Drying timber for aircraft	G.W.R. Co. ..	6,500
192. *Lancing*, L.B. & S.C.R. Co.'s Works	Timber Drying Kiln	1917–18	July, 1918	Drying timber for aircraft	L.B. & S.C.R. Co.	6,500
193. *Ladbroke Grove*, Barlby Road [London, W.].	Aero-Engine Factory.	Jan., 1918 (*n*)	—	Repairing aero-engines	Clement Talbot ..	141,700*

[1] Already in operation when nationalised.

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APPENDIX IV—*contd.*

Name and Address of Factory.	Class of Factory.	Date of Initiation.	Date of First Output.	Output.	Form of Administration.	Capital Expenditure to 31/3/18*
194. *Finchley*, Church End [London, N].	Balloon Factory ..	Jan., 1918 (*c*)	April, 1918	Balloons	(*a*) Sidney Davidson Balloon Co. & Davidson Aviation Co. (*b*) Direct Control.	£ 16,500*
195. *Greet* [Birmingham]	Radiator Factory	Jan., 1918 (*n*)	—[1]	Radiators for aeroplanes ..	Motor Radiator Manufacturing Co.	64,600
196. *Sudbury* [Suffolk]	Radiator Factory	Jan., 1918 (*n*)	—[1]	Radiators for aeroplanes ..		
197. *Berwick-on-Tweed*, Tweed Sawmills	National Sawmill	Feb., 1918 (*n*)	—	Sawing timber	Allan Bros. ..	5,900
198. *Kentish Town*, 23, Prince of Wales Crescent.	Optical Munitions Factory.	Feb., 1918 (*n*)	—[1]	Optical instruments	Control through Board of Directors.	80,000
199. *Southampton*, Empress Road ..	Gun Carriage Repair Factory.	Early 1918 (*c*)	Early 1918	Repairing gun carriages and breech mechanisms.	Direct Control ..	18,600*
200. *Mid-Lavant* [nr. Chichester][2] ..	H.M.E.F.	Spring 1918 (*c*)	—	Intended to produce acetate of lime .	Direct Control ..	86,700*
201. *Ludlow* [Shropshire][2]	H.M.E.F.	Spring 1918 (*c*)	—	Intended to produce acetate of lime ..	Direct Control ..	60,700*
202. *Walthamstow*, Black Horse Lane ..	National Gauge Factory	Spring 1918 (*n*)	—[1]	Gauges	Direct Control ..	5,500*
203. *Langley*	Chemical Warfare Factory.	Spring 1918 (*c*)	Sept., 1918	Chemicals	Agency ..	117,300
204. *Maidstone*	National Box Factory.	1918	—	Making and repairing tin boxes ..	Direct Control ..	—
205. *Luton*	National Box Factory	1918	—	Making and repairing tin boxes ..	Direct Control ..	—
206. *Guildford*, Walnut Tree Close ..	National Box Factory.	1918	—	Making and repairing tin boxes ..	Direct Control ..	6,000*
207. *Paisley* (*No.* 2), McKean Street ..	National Box Factory.	1918	—	Making and repairing tin boxes ..	Direct Control ..	4,400*
208. *Sheffield*, Bacon Lane	Casting Shop ..	April, 1918	—[1]	Bullets	Direct Control ..	1,200
209. *Birmingham* (*No.* 1), Lench Street[3]	National Rifle Factory.	May, 1918 (*n*)	—	Intended to make and assemble parts of Farquhar-Hill rifle	Standard Small Arms Co.	166,500*
210. *Birmingham* (*No.* 2), Garrison Lane[3]	National Rifle Factory.	May, 1918 (*n*)	—	Intended to make barrels of Farquhar-Hill rifle.	Standard Small Arms Co.	

211. *Gotham* [Notts.]	Concrete Slab Factory.	1918 (*c*)	—	Plaster slabs	King & Co. ..	16,600
212. *Yate* [Glos].	Concrete Slab Factory.	1918 (*c*)	June, 1918	Concrete slabs	R. McAlpine & Sons.	39,700
213. *Sandycroft* [nr. Chester]	H.M.E.F.	June, 1918 (*n*)	—[1]	M.N.T.	Direct Control ..	616,000*
214. *Brimsdown*, Green Street [Enfield, London, N.]	Photographic Lens Factory.	1918 (*c*)	July, 1918	Photographic lenses	Direct Control ..	6,000*
215. *Middlewich*	Chemical Warfare Factory.	Aug., 1918 (*n*)	—[1]	Making and charging poison gas ..	Direct Control ..	—
216. *Rainham*	Chemical Warfare Factory.	1918 (*n*)	—	Chemicals	Direct Control ..	40,200
217. *Holloway*, Batavia Mills [London, N.]	Anti-Gas Factory	Aug., 1918 (*c*)	Aug., 1918	Respirators	Direct Control ..	—
218. *Holloway*, Holloway Mills [London, N.]	Anti-Gas Factory	Aug., 1918 (*c*)	Aug., 1918	Respirators	Direct Control ..	—

[1] Already in operation when nationalised. [2] The factory did not reach the production stage. [3] Abandoned in October, 1918, before output was reached.

INDEX OF NAMES OF FACTORIES.

Key to Abbreviations.

H.M.E.F. = H.M. Explosives Factory.
N.S.F. = National Shell Factory.
N.P.F. = National Projectile Factory.
N.O.F. = National Ordnance Factory.
N.F.F. = National Filling Factory.
T.W.F.F. = Trench Warfare Filling Factory.
G.C.F. = Government Cartridge Factory.
N.A.F. = National Aircraft Factory.

VOLUME VIII

THE CONTROL OF INDUSTRIAL CAPACITY AND EQUIPMENT

PART III

ENGINEERING SUPPLIES

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CHAPTER I.

GAUGES.

I. The Use of Gauges.

It will be convenient to preface this section with a summary account of the use of gauges in modern manufacture, for though the principles involved are so familiar as to need no explanation, the precise application of them is not so well known. It is only within the last 30 years that limit gauges have been employed in large scale production by even the most progressive firms and institutions; at the outbreak of war they were practically unknown, except in their simplest and most rudimentary forms, throughout large parts of the engineering industry of this country.

(*a*) Interchangeable Parts.

Whenever a mechanism consists of several distinct parts it is necessary that these parts should fit each other properly. The simplest and most rudimentary way of securing the necessary fit is to hand over the entire manufacture of the mechanism to a single skilled craftsman, who will adjust the dimensions of each part by trial and error to suit those of the other parts into which it has to fit. This method is still employed in the manufacture of articles which are made in small quantities only, and in which the replacement of damaged parts is not likely to be necessary. The need for more advanced methods arose first in the making of such objects as bicycles, the parts of which are liable to separate damage, while it is inconvenient to return the whole to the maker to have the damaged part replaced. When there is likely to be a demand for spare parts it is clearly an advantage to make all the separate parts of the mechanism in such a manner that any specimen of a part of one kind will always fit adequately any specimen of the part of the corresponding kind with which it has to act in conjunction. Parts of mechanisms constructed in this manner are said to be "standardised."

But the advantage of standardised parts is not confined to mechanisms in which there will be a need for spare parts. It is found that great economies in manufacture can be attained by a specialisation which permits the substitution of machine tools for hand tools and of relatively unskilled for relatively skilled labour. In modern practice the parts of any mechanism that has to be made in large quantities are not all produced by the same craftsmen, constantly varying the operation which they perform, but by machine tools, each of which makes one part only (or even performs only a single operation in the

making of one part) under the supervision of an operative who may understand that tool and no other. Thus the time fuse of a shell consists of some 30 metal parts ; all these parts are made independently, not necessarily in the same factory, and are never brought into the neighbourhood of each other until the fuse is finally assembled ; but when they are brought together they have to fit.

(*b*) Limit Gauges.

There are two obvious methods by which this object might be secured. One way would be to tell the workman in inches the desired dimensions of the part he has to make, and to give him some means of measuring inches. The other would be to provide him with a part similar in all respects to that into which his part has to fit ; the part so provided would then be a " gauge " in all essentials. The method adopted resembles the second rather than the first. It differs from the second in two respects which are best illustrated by a simple example. Suppose the part to be made is a cylindrical rod which, in the completed mechanism, has to fit snugly into a hole bored in a block with its end lying flush with the surface of the block. Then the fit will be determined by two dimensions of the rod, its diameter and its length. Instead of giving the workman as a gauge a hole in the block which will gauge both these dimensions, we shall probably give him two gauges, each to gauge one dimension. One of these gauges will be a hole in a plate which will enable him to judge whether the diameter of the rod is right, independently of its length, the other will be some kind of parallel jawed calipers which will enable him to judge whether the length is right, independently of the diameter. The other difference arises from a more accurate definition of what is meant by " fit." If the hole in the block is 0·500 inches in diameter and 2·00 inches long, the rod will fit the hole exactly only if it also has these dimensions. But the complete mechanism will probably work quite well if the fit is not exact, and if the diameter of the rod is slightly less than 0·500 in., and the length slightly less or slightly greater than 2·00 in. The extent to which the dimensions of the rod may differ from those of the hole, without spoiling the fit for practical purposes, will depend entirely on the purpose of the structure. The permissible difference is called the " tolerance," and is negative when the part may be slightly smaller than the ideal dimension, positive when it may be slightly larger. For the sake of illustration, the tolerance on diameter in the example may be supposed to be —·01 in., and that on length +·03 in. or —·03 in. That statement means that the diameter of the rod may be anything between 0·500 in. and 0·490 in., the length anything between 2·03 in. and 1·97 in.

Accordingly the workman can be enabled to judge whether his work lies within the permissible limits without having to judge exactness of fit by providing him with two gauges for each dimension instead of one, the two gauges representing the extremes of the tolerance. Thus, in place of a single ring gauge for diameter he will be given two, in one of which the diameter of the ring is 0·500 in., in the other 0·490 in. ; if the rod will go into the first gauge and not into the second, then its

diameter must lie within the prescribed limits and will fit satisfactorily so far as diameter is concerned. For length, again, two caliper gauges will be given, one having a dimension of 2·03 in., the other 1·97 in.; the length of rod will be satisfactory if it will go into the first and no into the second. Instead of attempting to make his rod fit exactly into a single gauge, the workman need only reduce its length and diameter until it will go into the larger pair of gauges; a single test will then show if it will go into the smaller pair; if it fails to go, then the rod is satisfactory. Anyone who has any familiarity with handicraft will realise that this use of a pair of gauges increases greatly the ease and speed of production.

Herein lies the fundamental principle of limit gauges. Its characteristic features are, first, that separate gauges are used to fix different dimensions; second, that two gauges are used to fix each dimension differing in size by a definite amount. These two gauges are termed respectively the "go" and the "not go" gauges. In the example we have taken, the "go" gauge is larger than the "not go," but it will be seen readily that if we had been concerned with the diameter of the hole instead of that of the rod the gauge would have been a rod and the "go" gauge would have been smaller than the "not go." The applications of the principle are exceedingly numerous and vary greatly with the nature of the dimension to be gauged; in some of them one or other of the characteristic features may seem to be abandoned, but closer examination will reveal it. Both features tend to make the number of gauges required for any mechanism greater than the number of its parts. Since most parts are characterised by more than one dimension and each dimension generally requires two gauges, the number of gauges will almost always be more than double the number of parts. Thus the time fuse already mentioned, which has 30 parts to be gauged, requires 160 gauges for its construction. It will be readily understood, therefore, that the application of limit gauges is useful only when large numbers of objects are all to be made with the use of the same gauges.

There is no need here to mention many of the practical problems which arise in connection with the use of such gauges. But it will be well to note that the statements made about the dimensions of the gauges are not strictly accurate. It is difficult and laborious to make gauges, as to make any other objects, precisely to prescribed dimensions; and even if they were so made, they would soon wear and become inaccurate. Accordingly, gauges are usually made with their limits somewhat inside those determined by the tolerances, and some tolerance is allowed on the dimensions of the gauge. It will be seen that so long as the dimensions of the two gauges fall somewhere within the prescribed limits, and so long as the gauge which should be the larger is actually the larger, it will be possible to produce work which will lie within the prescribed tolerance; the only penalty of making the difference between the gauges less than the full amount allowed by the tolerance is that the limits within which the work must lie to pass the gauges are reduced and with them the speed of production. In the choice of the dimensions of the gauges a compromise

has to be made between, on the one hand, ease of making the gauge and allowance for wear and, on the other, ease of producing work which will pass the gauge. In the example taken of a ring gauge for the diameter of the rod, a tolerance of ·001 in. might be allowed on the gauges, the extreme limits of which might be ·002 inside the tolerance allowed on the work. Thus the " go " gauge would have to lie between 0·498 and 0·497, the " not go " between 0·492 and 0·493.

(c) INSPECTION GAUGES.

The gauges which have been considered so far are those supplied to the workman and are called " shop gauges." If shop gauges were always accurate and always used conscientiously, the work produced could be relied upon to be accurate and no inspection of the finished products would be required. But since these conditions are not fulfilled, inspection is necessary to see that the dimensions of the parts actually lie within the limits of the tolerances prescribed by the designer. Again, if gauges were made and could be kept exactly at the dimensions imposed by the tolerances there would be no necessary distinction between an inspection and a shop gauge ; any shop gauge which was known to be accurate might be used for inspection.

But, as was stated just now, the dimensions of shop gauges usually lie well within the permitted limits ; if such gauges were used for inspection they would reject work which did not exceed the prescribed tolerance. Thus, in the example the gauges would exclude rods of diameter 0·499 or 0·491 in., although such rods lie within the limits allowed by the designer. If all work is to be passed which falls within those limits no inspection gauge must have dimensions within those limits ; no " go " inspection gauge in our example must have a diameter less than 0·500 and no " not go " gauge a diameter less than 0·490. On the other hand, if the inspection gauge has dimensions outside the limits, it will pass work which may possibly not fit into the finished mechanism ; if an inspection gauge has a diameter as large as 0·501 it may pass rods which will not fit into a hole 0·500 in diameter. Ideally, therefore, an inspection gauge ought to be perfectly accurate ; and since this is practically impossible a choice has to be made between the chance of passing unsatisfactory work and that of giving a manufacturer a legitimate grievance. The former alternative is regarded as the less serious, and inspection gauges are allowed small tolerances outside the tolerance allowed on the work. Thus the inspection " go " gauge for the rod may be prescribed the limits 0·5005 and 0·5000 in., the " not go " 0·4900 and 0·4985. This alternative is selected because the chance of resulting error is so exceedingly small. It must be remembered that the hole into which the rod fits will be gauged as well as the rod ;. and that the reasons which lead the manufacturer to make his rods all slightly smaller than 0·500 in. will lead him to make all his holes slightly greater than 0·500. Accordingly, in order that a rod and a hole, each passed by inspection gauges, should fail to fit, three separate and very small chances must concur ; the gauges used by the makers of the rod and hole must both exceed their intended limits, the rod and the hole must both lie at the very limit which the shop gauges will

pass, and the exceptional rod must meet the exceptional hole in the process of assembling. Such remote risks cannot cause any serious trouble.

But it is important to realise that inspection and shop gauges are not interchangeable. The use of inspection gauges as shop gauges is impossible, not merely because the former are often somewhat more accurate and, therefore, more expensive to make (for when the tolerances on the work are relatively large there is usually no difference in the tolerances allowed on inspection and shop gauges), but because work made by inspection gauges would often fail to pass other inspection gauges. The dimensions of shop gauges always lie, or should lie, within the limits imposed by the designer's tolerances; the dimensions of inspection gauges always lie rather outside those limits.

(*d*) GAUGES AND DESIGN.

The tolerance allowed by the designer on any part of the work, or, more accurately, the tolerances allowed on a pair of fitting parts, varies enormously with the function of those parts. On the length of a large shell a tolerance as great as ½ in. may be allowed. To prescribe so large a tolerance may seem absurd, because there would be no difficulty whatever in making the length accurate within much closer limits; but here a large tolerance on length is allowed because there is only a very small tolerance on the weight of the shell, and the manufacturer can adjust the weight by altering the length. At the other extreme, the steel spheres made for ball-bearings are produced on the commercial scale with tolerances less than one ten-thousandth of an inch, which is probably the limit possible in large scale manufacture. The smallest tolerance allowed on any part of a shell or fuse is one thousandth of an inch, which is allowed on the diameter (0·078 in.) of the shearing wire of a percussion fuse. Here the necessity for accuracy arises not from a necessity for fit, but because the wire must shear when the strain on it reaches a certain figure. In certain parts of rifles, tolerances somewhat less than a thousandth of an inch are prescribed owing to the need for accurate fit.

A designer will always try to design his mechanism so that the tolerances may be as large as possible; for, of course, large tolerances mean quick and cheap manufacture. But it is gradually being realised that he must also consider questions of gauging. For, when the dimension to be gauged is part of a complicated structure, there may be considerable difficulty in finding a form of gauge which can be brought into the desired position. Thus a simple form of gauge which would be quite suitable for gauging the thickness of a flat plate could not be used to gauge the thickness of the wall of a nearly closed shell case; a much more complicated form would have to be introduced. It is sometimes possible by a slight change in the design of a part to render much easier the design of a gauge for it; and skilful designers and draughtsmen always bear in mind the necessity for gauging in making their designs. Many cases have occurred in the history of munitions manufacture in which slight changes of design have been introduced to facilitate gauging; and sometimes a choice has had to

be made between a form which is easy to manufacture but hard to gauge and one that is easy to gauge and hard to manufacture. Lack of foresight in this direction has only too often been a source of delay in production.

(*e*) Check Gauges.

By the use of limit gauges the workman is freed from the necessity of measuring his work in inches or comparing it with the primary standards of length. But such measurement and comparison must be undertaken at some stage of the process; it is merely transferred to those who make and certify the gauges. The gauges must be measured in the course of manufacture to ascertain when the correct dimensions have been attained; in practice they are always tested by some central standardising laboratory after they are made in order to avoid errors arising from carelessness or from imperfection of the standards with which they are compared.

Inspection and shop gauges are sometimes tested by a further application of the principle of limit gauges. When this method is adopted the testing gauges are known as "check gauges." For each dimension of the work which is to be gauged four check gauges are required, namely, a "go" and a "not go" check gauge for the "go" inspection or shop gauge, and a "go" and a "not go" gauge for the "not go" inspection or shop gauge. The check gauges must themselves be allowed some small tolerance, and the presence of this tolerance (like that allowed on inspection gauges) will again increase slightly the chance that work will be passed which will not fit into the mechanism; but check gauges are made with very great care, and the tolerance on them is so small that the additional chance of error introduced by their use is inappreciable. Nevertheless check gauges are used in connection with only a small proportion of all the gauges to be tested, because, for reasons already stated, they are economical of time, labour, and expense only when very large numbers of precisely similar gauges have to be tested. In shell and fuse manufacture some 9,000 different types of gauges were required; only about 20 per cent. of these were required in quantities so large that it was possible or desirable to make check gauges to test them.

When check gauges are not employed, the shop and inspection gauges have to be measured directly in terms of the standards of length. The standards employed for this purpose are almost always those made in Sweden by Johansson. These are plates or rods with surfaces or ends perfectly flat and parallel, so that standards of various lengths can be made up by simply placing two or more of the standards with their faces or ends in contact. The lengths of the various standards are so chosen that by suitable combinations of them a series of standards can be built up of any length between 0·2 in. and 8 in. (or more), each member of the series differing from the next member by 0·0001 in.[1] If

[1] The severe demand for these Johansson gauges experienced during the war led to several English firms undertaking the manufacture of similar plates, in which a considerable measure of success was obtained.

the gauge to be tested is one for measuring the length of a rod or the thickness of a plate all that is necessary is to find a combination of the Johansson plates which will just fit the gauge; the dimension of the gauge is then known from that of the combination which fits it. Modifications of this method are necessary when other forms of gauge are examined. For instance, if the internal diameter of a ring gauge is required two cylindrical rods are placed in the ring together with the Johansson plate, which will just fit between them. The diameter of the gauge is then the sum of the diameters of the cylindrical rods and the thickness of the plate. These diameters are found in turn by adjusting calipers so that the rods just fit into them and then finding a combination of Johansson plates, which will just fit into the same calipers. The principle involved is the exact opposite of that of limit gauges; in place of having separate gauges for each dimension, ingenuity is directed to using the same gauges to measure every different kind of dimension.

The tolerances allowed on gauges are, of course, as various as those allowed on the work, for it is only necessary that the former should be small compared with the latter. It is comparatively easy to make a gauge with a tolerance of ·001 in., and, except for the roughest work, larger tolerances are not prescribed. But when the tolerance on the work is only ·001, the tolerance on the shop gauge must be reduced to ·0002 or ·0003. When such small tolerances are allowed on the shop gauges, the tolerances on the inspection gauges will probably be no smaller; but when tolerances as great as ·001 are allowed on the shop gauge, only ·0005 may be permitted on the inspection gauge. The tolerances on check gauges have again to be small compared with those on the gauges which they have to check; in the example given they would probably not exceed ·0001 in. Lastly, the tolerances on the standards of length which are used for ultimate reference are always the smallest which are practically possible, and may be estimated at ·00001 in. It is possible to compare two standards of length to a much greater accuracy; with the greatest possible refinements applied to the most suitable standards differences of a few ten-millionths of an inch may be detected; but, of course, it is not possible to make a standard to a given length with the same accuracy as can be obtained in measuring that length.

(*f*) THE GAUGING OF SCREW THREADS.

Among the parts of mechanisms which have to fit accurately are screw threads. The application of the principle of limit gauges to such threads presents considerable difficulties. Hitherto we have been dealing with parts characterised by a small number of dimensions, which can be gauged separately and are such that the parts will not fit unless all the dimensions lie within the prescribed limits. A screw thread, on the other hand, is characterised by many dimensions, some of which are not easy to gauge, and which are such that an error in one dimension may compensate for an error in another. Thus, two of the most important dimensions of a screw-thread on a plug are the

diameter[1] and the pitch. If the diameter is correct, then the plug will not fit the nut unless the pitch is correct within certain limits, and *vice versa*; on the other hand, an error in pitch which would prevent the plug fitting if the diameter were correct will not prevent it fitting if the diameter is somewhat too small. Accordingly, if we attempted to assign definite tolerances to each of the dimensions, we should meet with a dilemma. If we assigned such small tolerances that the screw would fit even if all the dimensions were at the limits of the tolerances and all the errors worked in the same direction, we should exclude screws some of which would fit adequately because the errors, though outside the tolerances, did not work in the same direction. While, if we assign any larger tolerances, there will be a danger of passing imperfect screws if all the errors should happen to work in the same direction. And even if tolerances could be assigned definitely, each of the dimensions would have to be gauged separately. Since there are no less than seven dimensions which determine the fit of a screw, and some of them are by no means easy to gauge, the labour involved in separate gauging would be prohibitive.

However, it is fortunately found that in practice complete gauging is not required. For most purposes a pair of gauges, one "go" and one "not go," suffice to reject imperfect work. For a screwed plug the "go" gauge is a threaded ring with a screw of perfect form made to the larger limit of the tolerances; it will reject any screw which is too large. The "not go" gauge, which rejects plugs that are too small, is a plain cylindrical ring, which gauges only the full diameter of the plug. It is possible that a screw plug may pass both these gauges and yet have threads which are undesirably thin; consequently in some important parts (*e.g.* the screw which fixes the fuse in the shell) a second "not go" gauge is employed which bears only on the flanks of the thread and through which the threads will slip if they are too thin.

By this method it is found possible to provide gauges which in practice suffice to reject all unsatisfactory work, although a screw could be produced by deliberate intention which would pass the tests and yet fail to fit its nut satisfactorily. But in the making and testing of the gauges themselves much more elaborate methods have to be adopted. The methods of testing screw gauges which were in use before the war were very crude and generally quite inadequate; they either were insufficiently searching or required elaborate work by a skilled observer, which is quite impossible when large numbers of gauges have to be examined. The development of more satisfactory methods of testing screw gauges has been one of the most fruitful contributions of scientific work to the increasing of the production of munitions.

If it were merely required to reject unsatisfactory gauges a system of check gauges might be devised similar to, but rather more elaborate than, that used for testing the finished work. But it is desirable to inform the manufacturer not merely that his gauge is incorrect but in

[1] A screw-thread is characterised by three different diameters (*see* page 9); the statement in the next sentence is strictly true only if diameter here means effective diameter.

what feature it is incorrect, and for this purpose it is desirable to measure the essential dimensions separately. Machines suitable for workshop use have been devised for measuring the pitch of the screw, its full diameter, its core diameter (or the diameter between the bottoms of the threads) and its effective diameter (which is roughly the diameter of a section perpendicular to the axis of the screw); but in addition to these the shape of the thread is of importance and is difficult to measure mechanically. A convenient and accurate method of testing this shape was developed which depends on the comparison of the thread with a standard thread by optical projection. By suitable optical methods, essentially similar to those employed in the projection lantern of the kinematograph, a shadow of the screw can be thrown on a screen, in which all the dimensions are enlarged in the same ratio. This ratio is about 50, and is so great that any divergence between the shadow of the actual thread and that of an ideal thread in its immediate neighbourhood can be detected at once by the eye and measured by a simple scale. Such procedure is only directly applicable to screw threads on plugs where the thread is raised above the plug. In order that it might be applied to the sunken threads of nuts, casts of the thread were taken in plaster of Paris; the raised thread thus produced could then be examined by projection. Even when the greatest care is taken there is some loss of accuracy in making the cast, but no better method of testing the threads of nuts is known.

This method of projection has a notable advantage over and above those derived from its ease and accuracy. Many makers at first found great difficulty in producing screw gauges of the requisite form and, having no adequate means of testing them, were inclined to dispute the decision of the testing authorities when they were rejected. But seeing is believing; a visit to the laboratory and a demonstration of the difference between the shadows of the rejected and the ideal screw soon convinced them that their accusations were unfounded. It was largely owing to these improved methods of test, which enabled makers to be told where the faults of their gauges lay, that the percentage of gauges passing the test rose from 20 per cent. at the beginning of the war to 75 per cent. at the end of it.

(g) MANUFACTURE.

The making of gauges does not differ essentially from the making of any other metal object to a prescribed form; the only difference lies in the greater accuracy of the result which is required. The usual machine tools are used, lathes, milling machines, grinding and lapping machines, and so on, and the usual hand methods for the final adjustment. It is found that almost any skilled workman can produce gauges of any required form and accuracy, provided that he is provided with suitable means of measuring his work as it approaches completion. A testing department equipped with all the latest devices is necessary for the production of work of the highest class, and much of the work of the central testing departments has been concerned with advising manufacturers on the best methods of measurement for their special needs.

Their advice has been specially needed in connection with the making of screw gauges. Screw gauges, like all other screwed work, are produced by two methods, which are often combined. The first method is that of the screw-cutting lathe, in which a cutting tool is moved along the surface of the work, as it is rotated, by means of a "leading screw," usually operating through gearing, which forms an essential part of the lathe. The second method is that of the "tap" and "die." A tap is a plug of hardened steel, on which is cut a screw of some desired form, interrupted along lines parallel to the axis and provided with cutting edges, so that when forced into a plain cylindrical hole of suitable size it cuts a corresponding screw thread on the inside of the hole; a die is a screwed ring into which a rod can be forced so as to produce a corresponding thread on its surface. In both these methods the accuracy of the work produced depends on the accuracy of the tool by which it is produced. As soon as manufacturers all over the country were set to produce screw gauges it was found that the tools they possessed were surprisingly inaccurate; it was not uncommon to find screw-cutting lathes, supposed to be of a high class, in which the pitch of the leading screw was found to be in error by as much as 2 parts in 1000, an amount entirely impermissible in gauge work. These errors had often escaped notice because they would not affect greatly the fit of two threads produced by the same lathe, but only the fit of threads produced by different lathes. Excepting such very rough work as standard bolts and nuts, factories had only produced screws for their own use, and interchangeability with the work of other factories was unimportant.

An inaccurate tap or die can only be rejected, but inaccuracies in leading screws of lathes can often be corrected. In the early days of the war much of the time of the staff of the central testing laboratories was occupied in travelling about the country, setting up apparatus for testing screw-cutting lathes, and advising how the errors found might best be corrected. Their efforts not only made the production of large numbers of screw gauges possible, but also led to a permanent improvement in the accuracy of engineering work of all classes.

(*h*) Materials.

A word should be added concerning the material employed for gauges. As usually happens, the qualities which would be possessed by an ideal material are mutually inconsistent. It should be much harder than the material of the work to be tested, in order that it may not wear in contact with it; on the other hand, it should be easily worked. These qualities can, of course, be combined in some measure by using steel, which can be worked when soft and then hardened; but unfortunately the hardening is apt to produce distortion. This objection can be overcome to some extent, and was overcome in screw gauges, by hardening the steel on the surface only, case-hardening as it is called, but often hardening after making was not possible. Further, the supply of the most suitable forms of steel has been very limited, and what was available had often to be devoted to other objects; accordingly gauge-makers have actually used steels of all kinds from

plain carbon and mild steel to special alloy steels, their choice being dictated by what they could get rather than by what was best suited for their purpose.

It may be noted that for gauge work of the very highest class the gauge should be of the same material as the object gauged ; for if they are not of the same material they will expand and contract differently with change of temperature, and the gauge will be strictly correct at a single temperature only. But the range of probable temperatures has been so small and the permissible errors relatively so large in the manufacture of munitions that errors arising from this source could be neglected. But there was one consideration, not of a mechanical nature, which sometimes determined the material of the gauge. Picric acid, the explosive which, during the earlier part of the war at least, was largely used for filling shell, forms with iron a chemical compound which is liable to detonate with the slightest shock and explode the rest of the mass. Accordingly, the explosive must not be allowed to come into contact with iron ; and when shells already filled had to be gauged, iron was not permissible as the material of the gauge. In these cases a hard alloy called phosphor bronze was used, containing copper, tin and a little phosphorus, substances which are not so readily attacked by the explosive.

II. The Supply of Gauges.

(a) Supply prior to the Formation of the Ministry.

Before the war, all inspection gauges, with their corresponding checks, were made by the Ordnance Factories. Gauges for the inspection of guns and gun ammunition were kept at Woolwich Arsenal, where inspection of munitions for the most part took place. There were, however, several outstations, and to these examiners from Woolwich were sent when required with the necessary gauges. Inspection of small arms took place at Enfield Lock, where the gauges for these stores were kept. Contractors were responsible for obtaining their own shop gauges, which they either made in their own tool-rooms or bought from recognised gauge-making firms.

This simple system proved entirely insufficient to cope with the increased demand at the outbreak of war. While contractors continued to supply their own shop gauges, though with increasing difficulty and delay, the Chief Inspector soon found it necessary to decentralise inspection, and to extend the sources for the supply of inspection gauges The congestion at Woolwich, and the formation of local bonds for inspecting samples, made it necessary for inspection of gun ammunition to take place locally. The Ordnance Factories at first continued to supply the gauges, which were issued from Woolwich as required. but they could not manufacture fast enough to meet the demand (though their output went up 200 per cent. to 300 per cent.), and large orders had to be placed with gauge-making firms. By the middle of 1915 the number of inspection gauges required had grown far beyond the capacity of Woolwich, and contracts were being so widely placed that it was hardly desirable that a department which was not a contract

department should deal with them.[1] Accordingly, when the Ministry was constituted, it took over the whole question of gauge supply. Gun gauges were left in the hands of the Chief Inspector, and the supply of gauges for small arms was placed under the direction of Colonel Halse. The provision of gauges for gun ammunition and certain components was undertaken by the supply department for these stores (A.M. 3), which organised a special Gauge Section (A.M.3.D.) to deal with the question. On June 15th, 1915, Mr. M. F. Ryan was appointed head of the section. Its activities developed so rapidly that on May 16th, 1916, it was decided to organise it into a separate department (A.M.8) attached to D.D.G. (A), with Mr. Ryan as Director of Munition Gauges.[2]

(b) THE WORK OF THE GAUGE DEPARTMENT.[3]

As the output of shell and components is relatively much larger than the output of other munitions, the Gauge Department had by far the biggest problem to face. The gauges for gun ammunition are bewildering in their number and variety. For the body of an average shell about 30 different gauges are required. For components the number is, in many cases, considerably higher. The complicated mechanism of a time fuse requires 160 different gauges, and the simpler graze fuse requires 100.[4] Moreover, as one set of gauges can only deal with a certain number of stores, increased production involves a corresponding increase in the production of gauges. One set of inspection gauges for 6 in. shell should deal with about 1,500 shells per week, therefore a factory like the Lancaster National Projectile Factory, whose estimated output was 6,000 per week, would require at least four sets of inspection gauges for this nature of shell alone.[5] Some of these gauges would last for a considerable time without renewal, but others would be inaccurate after three weeks' night and day wear, and would then have to be replaced.

Thus the department had to provide gauges in great numbers, and of extraordinary variety. It concentrated its energies in the first place on the supply of inspection gauges. As regards the gauges required for miscellaneous stores for use at Woolwich itself, it was decided to leave these to the Chief Inspector, while the Gauge Department took over the supply for inspection of important stores, inspected chiefly at makers' works and local bonds. In July, 1915, it was found that enterprising firms were already making their own inspection gauges,[6] so it was suggested that the system should be extended, and all contractors and boards of management should be required to provide their own inspection gauges, as well as their own shop gauges.[7] They might either obtain them locally or through the Ministry of Munitions, who would supply them at practically cost price.[8] It was hoped that

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[1] 94/G/480.

[2] HIST. REC./R/263. 31/7.

[3] For convenience the term Department is used throughout to designate the Gauge Section of A.M. 3 as well as the Gauge Department, A.M. 8.

[4] *Ministry of Munitions Journal*, December, 1916.

[5] HIST. REC./R/1121/23.

[6] C.R./1306.

[7] 94/G/480.

[8] HIST. REC./R/1121/23.

the adoption of this system would lessen the congestion in gauge supply, which was now one of the chief factors in delaying output. The arrangement, however, which came into force in September, did not achieve its object; for most contractors found it impossible to obtain inspection as well as shop gauges locally, and applied to the Ministry to meet their requirements.[1] Where contractors attempted to make their own gauges, great delay ensued, for many of them were small and inexperienced firms with no facilities for such accurate work. Prices, moreover, were forced up, as the contractors expected to be paid for the inspection gauges out of the profits of the contract, and the number of rejections made the cost of the gauges extremely heavy.[2] In December, 1915, the system was once more re-organised. Contractors were no longer required to provide their own inspection gauges, which were in future to be obtained from the trade by the Gauge Department, verified by the National Physical Laboratory, and supplied to the Assistant Inspectors of Munition Areas, who would be responsible for maintaining sufficient supplies. Thus an arrangement, characterised by General Minchin as "a most objectionable system," was brought to an end, and contractors were freed entirely from the responsibility of suppplying their own inspection gauges. At the same time it was agreed that the gun ammunition gauges required at Woolwich and its outstations should be obtained also through the Gauge Department, and thus from January, 1916, the Ministry took over entirely the provision of inspection gauges for gun ammunition.[3] Contractors could, however, on application to the Department, still secure inspection gauges for shop inspection purposes; but these, though identical with inspectors' gauges, were stamped with a different certification mark by the National Physical Laboratory, to prevent their being used by Government inspectors.

At first shop gauges were left to the contractor as before, though the Ministry furnished guidance in design and construction where possible, and put contractors who could not make their own gauges into touch with gauge-makers who could supply their needs. In March, 1916, the Gauge Department undertook to supply shop gauges for the more important types of gun ammunition to contractors whose output was being delayed through inability to obtain them themselves; and, as soon as reasonable quantities of inspection gauges were forthcoming, it turned its attention to extending and organising this central supply of shop gauges. This was to some extent made necessary by the development of the National Projectile Factories, some of which required considerable assistance from the Gauge Department in obtaining their supplies, but it was also in the interests of rapid and economical production that shop gauges should be standardised and turned out in large quantities by a few firms with suitable plant instead of being produced as a bye-product by shell-makers. Accordingly in September, 1916, it was decided that standard gauges for all the more common

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[1] (Printed) *Weekly Report*, No. 7 (11 September, 1915), p. 17.

[2] 94/G/480.

[3] (Printed) *Weekly Report*, No. 23 (1 January, 1916), p. 16.

types of gun ammunition and components should be designed by the Gauge Department, manufactured by its contractors, and kept in stock for immediate issue.[1] The majority of these standard gauges were simple in design and easily and cheaply procurable, so that shell-making firms adopted them in many cases. By January, 1917, there was such a large demand for standard screw gauges that as a temporary expedient inspection gauges specially marked had to be issued to manufacturers for workshop use.[2] Firms who wished to continue using their own gauges were, however, allowed to do so, uniformity, though considered desirable, not being insisted on.

In the early part of 1916 the activities of the Gauge Department were extended to include the supply of gauges for trench warfare ammunition.[3] In February, 1917, certain branches of the Admiralty asked for assistance in obtaining gauges for mines. Large supplies were urgently required for the new programme, so the department undertook to give them special preference. The first delivery was made by February 17th, and in May it was reported that, with the exception of a few screw gauges, provision had been made for all the types required.[4] In February also the Aeronautical Engine Section asked the department to provide the gauges required for aircraft production, and this demand was also met without interfering with the supply for gun ammunition and components, the situation with regard to these gauges being well in hand.[5] Shortly afterwards the provision of gauges for gun repairs was included in the department's work. By the end of March the delivery of adjustable horseshoe gauges (*i.e.*, gauges of special form for parts not easily accessible) had begun, and gauges for the re-tubing and re-boring of guns were in hand. Special designs for certain gauges for the bore of guns had to be made, and orders for these gauges were placed with one of the Government factories.[6] Subsequently the supply of some of the gauges for new guns required by Woolwich was undertaken by the Gauge Department, as well as certain "special" gauges required by the Mechanical Transport Department, the Department of Requirements and Statistics and the Inspection Departments in France, Switzerland, United States of America and Canada, so that the supply of gauges of all kinds was mainly controlled by the Ministry.

(c) Development of Sources of Supply.

In view of the urgent demands for gauges which reached the Gauge Department from all quarters, the development of the sources of supply

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1 (Printed) *Weekly Report*, No. 59, III. (12 August, 1916).

2 *Ibid.*, No. 76, II. (20 January, 1917).

3 *Ibid.*, No. 24 (8 January, 1916), p. 17. Hitherto the Department had usually provided its own gauges.

4 (Printed) *Weekly Report*, No. 78, II. (3 February, 1917); No. 80, II. (17 February, 1917); No. 90, II. (5 May, 1917).

5 *Ibid.*, No. 78, II. (2 February, 1917); No. 79, II. (10 February, 1917).

6 *Ibid.*, No. 83, II. (10 March, 1917); No. 84, II. (17 March, 1917); No. 85 II. (24 March, 1917); No. 97, II. (23 June, 1917).

was a matter of primary importance. The Ordnance Factories continued to provide the gauges required at Woolwich, but only a certain proportion of the Arsenal needs could be supplied by them. In August, 1916, through the efforts of the Gauge Department, arrangements were made with the Chief Superintendent to extend the gauge shops at the Royal Laboratory, and a large new shop was installed which gave additional assistance both to the Arsenal and to the Gauge Department. But previous to this extension, the percentage of orders that could be executed by the Ordnance Factories was very small, and the Ministry had to rely on private firms for the bulk of its supply.

When the Gauge Department was set up, the few existing gauge-making firms were already executing orders to the limit of their capacity, and the Department had, therefore, to persuade a number of new firms to turn their energies to gauge-making. The big ordnance, machine-tool and machine manufacturing firms, with one or two notable exceptions like the Coventry Ordnance Works and the Singer Manufacturing Company, were doubtful as to the possibility of extending their manufacture of gauges, and the proportion of gauge orders placed with firms like Messrs. Armstrong, Whitworth, and Messrs. Alfred Herbert was extremely small. The latter firm has since, however, accepted large orders. The Department had, therefore, to adopt the policy of distributing orders over a number of firms, of which about 150 eventually succeeded in producing satisfactory work.[1] Though engineering firms of all kinds predominated, gauges were turned out in curious and unexpected quarters. The Gilmore Dental Appliance Works, Edinburgh, the Gillette Safety Razor Company, and the Victory Dress Fastener Company are examples of firms whose ordinary trade was far removed from the work which they undertook to assist the Ministry. Machine-makers of all kinds, such as the British United Shoe Machinery Company, Messrs. Cotton, Messrs. Mellor, Bromley, and Messrs. Gamble, hosiery machine builders, proved a reliable source of supply for the simpler types. Clock and watch makers and cycle and motor manufacturers were also very successful. Side by side with big manufacturers like the Coventry Ordnance Works are found individual craftsmen like Michael Pedersen, of Dursley, who designed and constructed new machinery in order to turn out screw gauges,[2] and E. A. N. Pochin, of Chelmsford, who took an order for rifle gauges, and met the Contracts Department's request to state his prices with the embarrassing reply, "I am absolutely ignorant of the figures which obtain for this class of work, and am perfectly satisfied to leave you to fill up the contract at any price which you consider fair."[3]

The railway companies were not overlooked as an additional source of supply, but though several companies made efforts to help, their plant proved unsuitable, and for the most part they abandoned the attempt. One company, the Lancashire and Yorkshire Railway,

[1] *Ministry of Munitions Journal*, December, 1916

[2] 94/G/1222.

[3] 94/G/1683.

succeeded in turning out satisfactory gauges, and the Great Western Railway was producing a small number of screw gauges at the end of 1917.

Educational institutions were also pressed into service. The Cambridge University Engineering Laboratory rendered yeoman service in making gauges for fuses of different types, while the University College of South Wales produced very satisfactory gauges of straightforward design.[1] Rifle gauges were made in large numbers by the Northampton Polytechnic Institute at Clerkenwell, and at the Manchester Municipal School of Technology.[2] In December, 1916, the L.C.C. Technical Institutes were delivering some 700 gauges a week,[3] and since then some of them have developed an output of difficult screw gauges.

The Post Office Factory and several municipal undertakings were another source of supply. In July, 1915, the Vice-Controller of Post Office Stores suggested to the Ministry that the tool-makers and highly skilled mechanics at the Post Office factory could be partly employed on gauges. The Ministry gladly accepted the offer, and orders for some of the more difficult gauges were placed.[4] The Glasgow, Preston and L.C.C. Tramways are examples of municipal enterprise, executing orders for gauges for components, shell, and Stokes bombs.[5]

The great difficulty experienced by the Ministry in obtaining enough screw gauges led to the opening up of foreign sources of supply. In June, 1915, a Swiss engineer resident in England offered to supply gauges if these could be made in Switzerland. After negotiations with the French Government it was decided that all Swiss firms and agents should make proposals through Mr. Angus, then British representative at Berne, who would act in concert with the French and Swiss authorities.[6] Diplomatic obstacles being thus cleared away, the Ministry placed orders in Switzerland with several firms, and satisfactory results were obtained from La Société Genevoise and, in certain instances, from M. Pierre Roch, of Berne. Swedish gauges began to come in at the end of 1915, the Department having been successful in securing the services of M. Johansson, the well-known maker, whose screw gauges were very satisfactory.[7] Several attempts were made to secure gauges from France and Holland at this time, and special visits were paid to these countries by representatives of the Department for this purpose. In 1917 the demands of the Aeronautical Department for metric screw gauges led the Ministry to send further representatives to France and Switzerland to persuade the leading gauge makers there to undertake these, while visits were also made to

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[1] Order and Supply Lists, Supplements 3 H, 7 H., 11 H.

[2] Order and Supply Lists, Supplements 3 H, 7 H, 11 H.

[3] *Ministry of Munitions Journal*, December, 1916.

[4] 94/G/420.

[5] Order and Supply Lists, Supplements 3 H., 7 H., 11 H.

[6] 94/G/360.

[7] (Printed) *Weekly Report*, No. 23 (1 January, 1916), p. 16; No. 51, III. (22 July, 1916); No. 31 (26 February, 1916).

American firms to secure their services in manufacturing screws of various types. In June the first consignment of metric gauges from France came to hand and was reported to be satisfactory, and this afterwards developed into a reliable source of supply. The prospects in America were less hopeful, as the Ministry's representative did not report very favourably on the facilities for manufacturing to the close limits specified. Orders were, however, placed with several firms,[1] and good deliveries were being made in March, 1918.

(*d*) DIFFICULTIES OF SUPPLY.

Apart from the general inexperience of makers, the difficulties which confronted the Department in obtaining large quantities of gauges were chiefly two :—

(1) The shortage of skilled labour.

(2) The lack of precision tools.

(1) Much of the work in gauge-making has to be to such fine limits that it can only be done by highly skilled labour. In the first twelve months of war this was at a premium, and, in addition, the actual number of experienced gauge makers was exceedingly limited. Consequently many firms refused to undertake the work at all, and others, who accepted gauge contracts, though very successful in other work, failed to produce satisfactory gauges, and had to ask for the cancellation of their contracts. Typical instances are those of Messrs. Braun & Company, who, when urged to take up the manufacture of rifle gauges in September, 1915, said it was practically impossible to get gauge-makers and first-class fitters and turners, and the Power Plant Company, who asked to be relieved of a contract for gaine gauges because they found it impossible to get men to do the work.[2]

Another result of the labour difficulty was the inability of firms to give the delivery required by the Ministry. In order that the work might be put in hand as quickly as possible, the Gauge Department sent firms an authorisation to begin work before the formal contract was signed.[3] In this "Gauge Order," the approximate date by which delivery was to be completed was stated. For an order of 20 to 50 gauges six weeks from the date of the receipt of the official drawings was a common time specified. But the extreme accuracy required by the Inspection Department made it impossible for makers to do more than rough out the bulk of the gauges until their samples had been passed. Thus in many instances the time specified in the gauge order had elapsed before any appreciable amount of work had been done, and the date of delivery had to be reckoned from the passing of the samples rather than from the receipt of the official drawings. For instance, on 28th July, 1915, Messrs. Burton Griffiths & Co. were

[1] (Printed) *Weekly Report*, Nos. 88, 90, 91, 97, 98, 100: Section II. (April-July, 1917).

[2] 94/G/590/512.

[3] See Appendix I.

authorised to put in hand three different types of gauges, delivery of which was to be completed in six weeks, and tender forms were issued in the usual way. After several requests from the Ministry, the firm forwarded the tender for one type with the date of delivery inserted as 9th October. When asked for the others they replied that, as the gauges were most difficult to manufacture and those turned out had not yet passed the National Physical Laboratory test, they could not quote either definite delivery or price. On 10th November these two orders had to be cancelled.[1]

As makers gained experience the labour difficulty was to a large extent overcome. Firms were pressed by the Ministry to dilute their skilled labour, and in most cases did so with good results. Women and boys were put on to rough out the gauges,[2] which were afterwards finished to the required limits of accuracy by skilled men. This plan was adopted by Messrs. Chatwin, at whose works women did the roughing out to within ·006 of an inch.[3] In some factories, as at Messrs. Pitters, where screw-cutting lathes were worked by women, the women, under the supervision of skilled men, were able to perform many of the finishing operations as well,[4] and showed themselves capable of cutting threads correct to ·0003 in.[5] At the end of 1918, about 80 women were employed in the Wolseley National Gauge Factory on what was previously considered skilled men's work. In many instances, manufacturers were able to train their ordinary mechanics to the higher skill necessary for gauge-making (*e.g.*, Messrs. Pitters and the Wolseley Motors, Ltd.), and this helped to relieve the situation. The labour supply, however, must always present somewhat of a problem in gauge manufacture owing to the high degree of skill required.

(2) The second great difficulty was that precision machinery, such as accurate lathes and grinders, was practically non-existent, and could not easily be procured. This was especially the case with regard to screw-gauge machinery, as before the war the manufacture of screwed parts to fine limits was not customary to any great extent in England. Thus, though there were firms willing to undertake the simpler types like plug and ring gauges, very few would take orders for screw gauges. Orders for complete sets were therefore hardly ever placed. In August, 1915, Messrs. A. Herbert executed an order for 50 complete sets of fuse 100 gauges at a total cost of £954 12s. 11d., and Messrs. Barber & Coleman took a similar order at £966 16s. 10d.[6] But in general orders were placed with different firms for the particular types of gauges most suited to their plant and the skilled labour at their disposal, the quantity ordered varying as a rule from 10 to 100 of a type.[7]

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[1] 94/G/478.

[2] The introduction of women into the actual work of gauge-making was comparatively late, being tried in the latter part of 1916, and considerably developed during 1917. Women were, however, employed to examine the gauges when made early in 1916.

[3] L.I.B./C/309/1. [4] L.I.B./C/778/1.

[5] *Ministry of Munitions Journal*, November, 1917.

[6] Order and Supply Lists, Supplement 3 H.

[7] See Appendix I.

In time certain selected firms developed a much larger output *e.g.*, orders running into thousands were placed with the Coventry Ordnance Works and the Newall Engineering Company in January, 1916.[1]

The Gauge Department did its best to assist makers by getting machines from abroad, especially from Switzerland, but these were quite insufficient to meet the demand. Home sources of supply were next developed, Messrs. Alfred Herbert and others giving assistance in this respect. Simplified precision machines were designed and built, and this has resulted in the possibility of producing gauges, particularly screws, in several ways. Messrs. Pitter's experience may be quoted as an example of the effect on output of these machines. The screw-cutting machine designed by Mr. Pitter and installed in his new work-shops cut eighteen to twenty soft steel screw gauges a day, whereas the men working on ordinary lathes in the old shops were only able to produce one or two a day.[2]

As a result of these improvements and of the Department's policy of concentrating the entire energies of the most successful makers on screw gauges, the difficulty has been to some extent overcome, and a more than sufficient supply would have been available had it not been for heavy but unforeseen demands for screw gauges for aero-engines. The home output could, however, be materially increased if more precision plant were available.

(*e*) Financial Arrangements.

Though the Ministry encouraged makers in every way by giving expert advice in manufacture, assistance in obtaining machinery and material and "sympathetic consideration" to requests for extension of time for delivery, many contractors were unwilling to develop gauge-making because they felt that if they took orders on the ordinary contract basis, they would lose heavily owing to the number of rejections they would inevitably have at first, and to the large amount of time and material wasted in manufacture. To meet this objection the Ministry adopted the system of payment on the cost and percentage profit basis. Firms who had not manufactured gauges before were offered contracts on the basis of "actual labour cost, plus 100 per cent. for overhead charges, plus costs of material, plus 10 per cent. on the total." Thus contractors were safeguarded from loss on labour and material, and were guaranteed a certain margin of profit. The majority of the early orders were placed on this basis, though fixed prices were adopted in the case of large and experienced firms wherever possible.

After a short experience of these contracts firms began to raise objections to them on the ground that 100 per cent. was not necessarily sufficient for overhead charges ; and, in some cases, they also considered the profit allowed insufficient. As a rule when complaints of this kind were received, the Ministry offered to substitute a contract at a fixed price if the firm would quote figures. In July, 1915, several firms

[1] 94/G/1129/1298. [2] L.I.B./CE/778/1.

changed from cost plus percentage contracts to contracts at a fixed price,[1] and this was constantly occurring during the next few months. This did not, however, entirely meet the case of inexperienced firms. Many who found 100 per cent. overhead charges insufficient could not quote fixed prices as they had no data on which to work, or if they quoted, they made such big allowances for contingencies that the price named was excessive. Accordingly, the terms of payment in the cost plus percentage contracts were altered. This was done at first only in exceptional cases. Thus, an increase in overhead charges was sanctioned in the case of the Wolseley Motors, Ltd., who were allowed 125 per cent. for overhead charges early in 1916; and an increase in profit was sanctioned in the case of a South Tottenham contractor, who was allowed 15 per cent. profit on a contract for rifle gauges.[2] Such changes were made necessary either by the intricate nature of the gauges or by the difficulty of obtaining adequate supplies. In March, 1916, this widened interpretation of the cost plus percentage contract was given a general application, the clause defining the payment to be made running as follows: "Actual *productive* labour cost, plus *such percentage thereon as represents the proportion of the actual overhead charges applicable to such labour cost,* plus *net* cost of material, plus 10 per cent. on the total." In specific instances, however, makers preferred to have the percentage still definitely fixed at 100 per cent. This was the case with the Cambridge Engineering Laboratory and the Perforated Music Company. The Ministry complied with their wishes, the Auditor remarking with regard to the latter that "the Ministry will be well advised in accepting 100 per cent. as the rate of on cost. The actual rate is considerably more."[3]

The cost plus percentage contract was only adopted to meet a difficult situation, and the Ministry's policy was to eliminate it as much as possible. As soon as firms had had a fair amount of experience in making a certain type of gauge, they were asked to quote a fixed price on repeat orders. Between July and September, 1915, the majority of orders were placed on the cost plus percentage basis, but by March, 1916, fixed prices predominated. An example may be quoted in December, 1915, when the Pitter Engineering Company wished to execute a repeat order on the cost plus percentage basis. The Ministry said, however, that as the firm had had considerable experience in the manufacture of the type of gauge ordered, they should be in a position to quote, and the order was placed at a fixed price.[4] On the other hand, the Ministry permitted some firms to continue on the cost plus percentage basis. In January, 1916, Messrs. Bassett Lowke were asked to quote, but were afterwards allowed to do the work on the cost plus percentage basis, the reason apparently being that, as labour was cheap at Northampton, the percentage basis was as economical as the fixed price.[5] With regard to the Gilmore Dental Works, who asked that *all* orders should be placed on the cost

[1] 94/G/389.
[2] 94/G/1215/1401.
[3] 94/G/1295.
[4] 94/G/1078.
[5] 94/G/1071/1315.

plus percentage basis, the Auditor said it was most advisable to continue the arrangement, " in every case their prices are lower than any other contractor."[1]

In the case of contractors who had few rejections, the price on the cost plus percentage basis worked out very reasonably, but when contractors had gauges returned two or three times, and the Ministry had to pay for the labour required to rectify them as well as for the material wasted in manufacture, the cost plus percentage arrangement was very extravagant. At the end of May, 1916, it was laid down as a general rule that " only very special circumstances . . . . can justify any proposal to pay contractors on a basis of cost, plus percentage of profit."[2] An exception was made in the case of gauges, owing to the special character of the work, but the Finance Department expressed its opinion that the number of these contracts should be kept as low as possible.[3]

The definite fixing of prices gave the Ministry an opportunity of trying to reduce prices, and provided a basis of comparison. On the whole the prices quoted were fair and reasonable, but in a minority of cases they were high, and the Ministry then asked for a reduction. In some cases the firms acceded to the request without any demur. On 15th March, 1916, for instance, Messrs. G. Cusson, Ltd., tendered for 25 6 in. shell caliper gauges at £12 each, but as Horstmann Cars, Ltd., were doing the same gauges at £8 15s. each, the Ministry suggested a reduction of £2 per gauge, and this was accepted by the firm.[4] But often firms refused to alter their price, saying that the intricate nature of the work and the extreme accuracy required made it impossible to make the gauges for less. In the early days of the Ministry, if firms stood out for their prices the Ministry had to accept them, owing to the urgent need of the gauges and the impossibility of obtaining them elsewhere. Thus, in August, 1915, the Gauge Department objected to the prices quoted by Messrs. Muir and Company for screw gauges. The firm answered that rather than do the work at a lower price they would not take the order at all, whereupon the department had to accept their terms.[5] In October a contract was placed with the British L. M. Ericsson Company at relatively high prices, because, as the department stated, " we may not get the gauges elsewhere in time."[6] Again, in November the Ministry had to accept the terms offered by Messrs. Tilling Stevens, because there was no other contractor who would make the particular type of gauge required.[7] As the organisation improved, and the sources of supply grew more assured, the Ministry was able to fix maximum prices successfully. It is difficult, however, to show how far the reduction in price was really steady, partly because contracts for the same gauge were placed sometimes at fixed prices and sometimes on the cost plus percentage basis, and

[1] 94/G/1836.
[2] 94/G/2199.
[3] 94/G/2199.
[4] 94/G/1556.
[5] 94/G/546.
[6] 94/G/756.
[7] 94/G/978.

partly because individual circumstances, numbers ordered, and urgency of delivery affected prices considerably. The Ministry's policy was to induce individual firms to lower their prices as they gained experience and were able to execute larger orders, rather than to make all firms conform to a uniform standard, which would obviously have been an unsound policy. The general tendency of prices was downwards, and by the end of 1916 average prices were considerably lower than those ruling in 1915.[1]

Contracts other than those with the trade were placed on varying bases. The University Engineering Departments and the Technical Institutes took contracts either on the cost plus percentage basis or at fixed prices.[2] Orders with foreign firms were placed at a fixed price, generally with the proviso that 75 per cent. or 80 per cent. should be paid on delivery and the remainder after the gauges had passed test in England.[3] Orders with Railway Companies were placed through the Railway Executive Committee at agreed prices.[4]

(*f*) The Supply of Raw Material.

In general tool or high grade steel is used for making gauges, which have hardened working surfaces; but during 1917 and 1918 the practice of making gauges of mild steel and then case hardening them found greater favour on account of the reduced cost of material and the greater ease in machining mild steel. In the early stages of manufacture screw gauges, with certain exceptions, were not hardened, but as a result they lost their accuracy very soon and had often to be renewed. It was found impossible to procure hardened screws in any quantities because so few firms had the necessary experience. Hardened gauges were also considerably more expensive, as is shown by the fact that a gauge made by Messrs. Bassett-Lowke for £2 2s. (unhardened) cost £4 5s. when made by the Coventry Ordnance Works with its working surfaces hardened. As, however, the hardened gauge would last three or four times as long as the soft one, the price was pronounced reasonable by the Gauge Department.[5] In certain cases arrangements were made to have screw gauges toughened by a process invented by the Westminster Electrical Testing Laboratory, with the result that the life of the gauge was considerably prolonged.[6]

The need for economy and the difficulty experienced by many firms in obtaining steel led to experiments being carried out by the Lea Foundry Company in 1916 with the object of substituting chilled cast iron for steel in the manufacture of ring and plug gauges. In September, 1916, the result of the experiments was reported to the Gauge Department. A few of the gauges had been successfully ground and passed, but most had failed owing to the hardness of the material. Moreover, the amount of personal attention required made

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[1] See Appendix II.

[2] Order and Supply Lists, Supplements 3 H, 7 H. and 11 H.

[3] 94/G/483/1020/1842/1902.

[4] 94/G/481.

[5] 94/G/2316.

[6] 94/G/1801.

most gauge makers hostile to the idea, and it was decided to abandon it.[1] Another attempt to use cast iron was made in 1917, when it was reported that the firm was successfully producing cast iron gauges of various kinds,[2] but it was eventually dropped as being unsatisfactory. Cylinder gauges have, however, always been successfully made in large quantities of cast, but not chilled, iron.

(g) Summary of Output.

Between August, 1915, and December, 1917, approximately 760,000[3] gauges, comprising 14,500 different types, were delivered by contractors to the National Physical Laboratory for testing. This figure does not represent the total output of gauges for the period, since all rifle gauges were sent to Enfield Lock, and gun gauges, as well as certain gun ammunition gauges, went straight to Woolwich. On the whole the average weekly delivery per month shows a steady increase. In January, 1916, it was approximately 3,330 and by December it had reached 5,530. In July, 1917, the delivery reached high-water mark, the weekly average for the month being 11,015. During the remaining five months of the year there was a slight decline, but the average weekly delivery remained in the neighbourhood of 10,000. During 1918 there was a decided decrease in the numbers of gauges dealt with by the National Physical Laboratory. The highest weekly average was 8,000 in January; by October it had fallen to 6,600; while after the signing of the Armistice there was a quick drop to 4,700 in December, 1918. Approximately 326,000 new gauges of different types were tested during the year, 73 per cent. of which passed, compared with 75 per cent. in 1916 and 1917. The slight falling off in efficiency in manufacture in 1918 was probably largely due to the greatly increased dilution of labour during that year.[4]

III. National Gauge Factories and Assisted Contracts.

In spite of the progress in manufacture made by many firms, the obvious weaknesses inherent in the system of spreading contracts for small quantities of gauges over a large number of firms, together with the paramount necessity of increasing the supply of screw gauges, led the Department to consider the possibilities of greater concentration in manufacture and more rigid control over the producing factories. As early as July, 1915, the establishment of a Central Gauge Factory was suggested,[5] and on several other occasions the idea received serious consideration. But when it was first brought forward, the urgency of supply was so great that the time required for building and equipping such a factory, and the difficulty of finding the necessary

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[1] 94/G/1558.

[2] *Ministry of Munitions Journal*, March, 1917.

[3] N.P.L. Statistics.

[4] Appendix III. The figures given here and in the tables in the Appendix can only be regarded as approximate.

[5] C.R/971.

staff, made its adoption impossible. Though these obstacles disappeared to some extent later, the scheme was never carried through, as it was felt that the interests of production would be better served by selecting certain of the successful makers and aiding them to extend their works and improve their output.

This policy resulted in the establishment of National Gauge Factories. Generally speaking, the buildings of the selected firms were taken over and in many cases extended, and their organisation was controlled and financed by the Ministry. But the agreements varied very considerably in detail to meet the widely different circumstances of the managing firms, and the result was that, as time went on, it became uncertain as to whether certain factories were National Factories or merely Controlled Establishments. In February, 1918, the Controlled Establishments Division stated that " the principle on which this Department has proceeded is that when the factory is carried on on behalf of the Government it is properly considered a National Factory . . . . but that where merely the whole output is taken and the firm paid for that output, the premises do not constitute a National Factory."[1]

Under this definition the term National Factory embraced six factories in all—the Woolwich National Gauge Factory, the Birmingham National Small Tools Factory, and the Croydon, Wolseley, Fairfax, and Newall National Gauge Factories.[2] It should be noted, however, that the National Gauge Factories were not on quite the same footing as the new national factories devoted to the production of ammunition, since they were not fresh organisations unconditionally established and owned by the Government. A central gauge factory, had it been established, would have been a national factory of this type ; as it was, the nearest approach to such a factory was the Fairfax Gauge Factory, established directly by the Ministry in 1917.

(a) The Woolwich National Factory.

The works owned by Messrs. Pitters Ventilating and Engineering Company were the first to be placed under Government control. The first agreement, which was in July, 1915, only gave the Ministry partial control over the firm's activities, so a second agreement was made in August, 1916, which placed the firm's entire output in the hands of the Ministry. By the first agreement the firm was to erect new gauge-making shops (Brewer Street Works) adjoining their own private works. These new shops were to be entirely separate from the old works, and the whole output was to be under the control of the Ministry. The Government was to find the money for the erection and equipment of the buildings and for the working expenses of manufacture, excluding, however, the directors' fees and the managing director's salary. For profit the company was to have 20 per cent. of the total sum paid as wages and salaries by the Ministry.[3] By the second

[1] M.F./Genl. /1422. [2] M./Demob./21.
[3] D.D.G. (A)/15828.

agreement it was arranged that the Ministry should also take over the company's private works (Market Street Works). As, during the year 1915-1916, the Company had become involved in financial difficulties, the financial arrangements were put on an entirely new footing. The Ministry took over all the assets and trade liabilities of the firm, lent them a sum of £5,000 to clear their overdraft at the Bank, and, as remuneration for their services, agreed to pay them a sum of £2,000 a year with a bonus of £500 a year for economical working. Directors' fees and the managing director's salary were to be paid by the company as before, and one of the directors of the company was appointed a special financial director with an additional salary also to be paid by the company. The Ministry appointed a chairman, who was to act as its representative and control the company in its interest. The agreement was to remain in force for a period of five years from 1 April, 1916, but if the war should end before 1 April, 1919, the Minister might terminate it by six months' notice in writing. Such termination was not, however, to take place before 31 March, 1919. When the agreement came to an end the company was to have the option of purchasing the works at their current value, and was to repay the £5,000 loan in four annual instalments.[1]

In January, 1917, Messrs. Pitters were instructed to build an addition to the works for the purpose of making screw gauges, by means of a special machine designed by Mr. Pitter, which could be worked with unskilled labour. In this extension, which was completed by May, 1917, space was provided for 24 machines, but only 12 were installed at first to see if the output would prove satisfactory. A great deal of difficulty and delay occurred, the principal obstacle to success being that, as the supply of gauges increased, manufacturers refused to take the soft gauges made on the Pitter machines, and hardening had to be taken in hand. By the end of 1917 the chief difficulties were overcome, and during 1918 the additional machines were installed with a corresponding increase in output. During the summer of 1918 a further extension was planned for the purpose of making block gauges of the Johansson type, but the work, which was put in hand in October, was stopped on the signing of the Armistice.

No definite agreement had been made with the firm in connection with the extension of 1917, so in August, 1918, the Ministry put forward a draft agreement to cover this and the scheme for the new extension. Briefly put, this proposal was that the company should abdicate from its position as manager, and that the Ministry should take over the whole factory, carrying it on as a true National Factory under a manager (still to be Mr. W. C. Pitter) appointed by itself, and paying a rent for that part of the buildings and machinery owned by the company. After the termination of the agreement the company was offered the option of taking back from the Ministry the whole of the factory, including Government property as well as its own, on certain fixed terms.[2] This proposal was declined by the company, and therefore, when the

[1] D.D.G. (A)/15828.

[2] Unregistered memo.

Armistice was signed in November, 1918, the agreement of 1916 was still in force for the Market Street and Brewer Street Works, and no agreement had been come to with regard to the later extensions. The factory continued to make gauges (chiefly for aeroplanes) until the spring of 1919, when the Ministry began negotiations with a view to arriving at a settlement with the company.

(b) THE BIRMINGHAM NATIONAL SMALL TOOLS FACTORY.

The agreement made with Messrs. Chatwin, of Birmingham, in September, 1915, was a much simpler one. Messrs. Chatwin were to extend their premises at a cost of £8,000, of which 70 per cent. would be repaid by the Ministry. The Ministry was to take over the control of the works from August 31st and advance working capital, and also take the entire output, as soon as the firm had completed outstanding contracts. Payment was to be made every six months on the basis of valuation of stock and work done, plus 15 per cent.[1] The Ministry was to appoint a Director to look after its interest.[2] From 1915 to the signing of the Armistice the factory was carried on under these conditions, though the capital expenditure considerably exceeded the £8,000 originally agreed upon. By December, 1917, it had reached £11,000 and it was estimated that it would reach a total of £12,000.[3] A greatly increased output was the result as well as a considerable profit to the Ministry. Of the six National Factories this was the only one where it was possible to ascertain the actual profit made. The greater part of the output of this factory consisted of small tools, taps and dies, and these were supplied at the Ministry's instructions to contractors engaged on munition work, and charged to them at standard trade prices. The profit made was, therefore, ascertainable in the same way as that of a private business. The whole output of the other five factories was sent to the National Physical Laboratory at Teddington, to Enfield, or to Woolwich, where the gauges were invoiced at cost, plus 10 per cent. profit. Thus the profits are shown as a percentage on the turnover, and no actual figures are obtainable.

After the signing of the armistice it was arranged that Messrs. Chatwin should resume control of the factory from 31 March, 1919. The reversion of the factory to the private owners was in this case a comparatively simple matter, since the work carried on during the war was the firm's normal business, and it was, therefore, simply a matter of financial settlement between the firm and the Ministry.

(c) THE CROYDON NATIONAL FACTORY.

Negotiations with regard to the Croydon National Gauge Factory were started in November, 1915. The factory was originally owned and worked by Pintsch's Electrical Manufacturing Company, which was of German origin. As it had a skilled management and staff capable of producing most difficult gauges, the Ministry was approached to take it

[1] 94/G/707. [2] L.I.B./C/309/1. [3] C.R./2913.

over and carry it on as a National Factory. It was thought, however, that objections might be raised to the provision of funds for a business with German connections, and so the offer of a Mr. Pugh to form a company, which would be known as the Vidal Engineering Company, to take over the factory, finance it, and carry it on under the supervision of the Ministry was accepted.

According to the agreement of 1915, the company was to lease premises and provide a capital sum of not less than £5,000 or more than £10,000 for carrying on the manufacture of gauges, such capital to be treated as bearing interest at 1 per cent. over the current Bank of England rate. Provisional prices were to be fixed between the Ministry and the Company, whose books were to be open for inspection. Accounts were to be rendered and paid monthly. At the termination of the agreement any surplus profit was to be paid to the Ministry, and any loss would be made good by the Ministry. The Ministry could dispense with the company's services at any time by repaying the capital and taking over all liabilities.[1]

The financial arrangements were slightly modified in May, 1916. The provisional prices fixed by the firm were always considered far too high by the Ministry, and in March the Finance Department suggested that Mr. Ryan should fix the provisional prices. This was done on the next orders, but in May the company protested that to do the work at the prices proposed would involve them in a direct loss, as the establishment charges (which included writing off the machinery at the rate of £200 a month as agreed by the Ministry) were very high. To meet the difficulty, it was decided to pay for all gauges in future on the basis of productive labour, plus the ascertained on-cost, materials, and 10 per cent. of the whole amount for profit.[2]

Early in 1917 it was decided to extend the works. This decision, together with the fact that the company's expenditure had by this time considerably exceeded the £10,000 originally stipulated, and that Mr. Pugh had received nothing for his services beyond the agreed interest on capital expenditure, necessitated the drawing up of a fresh agreement. It was some time before satisfactory terms could be arrived at, so Mr. Pugh sent in a claim for remuneration for his past services, and was awarded £1,000 by the Lubbock Commission. The agreement, which was finally signed in October, 1917, cancelled the agreement of November, 1915. The existing arrangements with regard to the lease of the premises were to be continued, and also the agreement with Mr. Vidal to act as manager. Capital up to £30,000 was to be provided by Mr. Pugh, who was to continue to work the factory as agent for the Ministry. Either party to the agreement might terminate it and the capital would then be repaid. The price to be paid for gauges was the cost of labour and materials and overhead charges, plus 10 per cent. on the total as remuneration to Mr. Pugh for his services. At the termination of the agreement any surplus on the working of the factory after all liabilities had been discharged was to be paid to the

[1] 94/G/1087. [2] 94/G/1378/1943.

Ministry, while equally any deficit shown would be made good by the Ministry. Upon the repayment of the capital advanced and the discharge of liabilities all the plant, machinery and buildings erected by the Ministry would become its property. Mr. Pugh was to have the option of building, entirely at his own expense, a permanent addition to the factory, instead of the temporary one proposed by the Ministry, which permanent building would remain his property on the termination of the agreement.[1]

When work was started on the new building, it was found that the land on which it was proposed to build it was unsatisfactory. Mr. Pugh, therefore, put forward a proposal for building an entirely new factory in another place. This offer was accepted, and the October agreement was modified in November to meet the new situation. The lease of the Gloucester Road premises was to be ended, and the plant and machinery belonging to Pintsch's Electric Manufacturing Company, together with all the machinery belonging to the Ministry and some temporary buildings at Gloucester Road, were to be removed to the new factory, which was to be built at Mr. Pugh's expense and to remain his property on the termination of the agreement. Mr. Pugh was to undertake all responsibility for the arrangements with Pintsch's Electric Manufacturing Company. The Ministry agreed to pay a rental of £1,025 a year (the sum which had been paid up to this point to Messrs. Pintsch for the use of their premises and plant) for the use of the plant and machinery and new buildings, in addition to all other payments made under the existing agreements.[2]

In February, 1919, Mr. Pugh gave notice to terminate the agreement.

(*d*) Wolseley National Factory.

Under the agreement with the Wolseley Motor Company made in January, 1917, the company's factory at Pimlico was to be carried on as a gauge factory under the direction of a representative of the Ministry. The Ministry agreed to take over all the buildings that had been erected and all the plant that had been installed since September 30th, 1914, as well as the consumable stores and the gauges in the course of manufacture which were in the factory on January 20, 1917. The total sum to be paid for these items was £24,768 2s. 9d. The pre-war plant and buildings were to remain the property of the company, though the Ministry was to have the use of them. From January 20, 1917, the Ministry was to bear the cost of working and maintaining the factory, paying to the company £1,186 a year in respect of depreciation of pre-war plant and buildings, and as profit a sum of 20 per cent. per annum on the capital cost to the company of the pre-war plant and buildings, which was reckoned as £12,010 12s. 4d. As the company was, at the time of the agreement, making gauges for Messrs. Vickers, it was agreed that they should continue to do so at the discretion of the Ministry, all payments for such gauges being made to the Ministry. The agreement was to be binding for the duration of the war, but the

[1] 94/G/1000. [2] W.B./657.

Ministry reserved the right to terminate it at three months' notice if necessary. At the termination of the agreement all property belonging to the Ministry might be removed, and the premises as well as the plant belonging to the company were to be handed over in good repair.[1]

When the Ministry took over the factory, the plant was increased to double its previous capacity and was further added to afterwards, with a corresponding increase in output. On the signing of the Armistice notice was given to terminate the agreement, and the factory returned to its former business of motor-car repairing.

(*e*) FAIRFAX NATIONAL FACTORY.

The Fairfax National Gauge Factory was established in May, 1917, to utilise skilled enemy labour in the production of check and other difficult gauges. Existing buildings at Kilburn were rented and added to by the Ministry, and operations were begun under the management of Mr. W. J. Bassett-Lowke, whose firm was already doing a great deal of gauge work. As far as the financing and auditing of the accounts were concerned, the factory was worked as an adjunct of the Wolseley National Gauge Factory. About 15 men were employed, with most satisfactory results from the point of view of production.

After the Armistice was signed the Home Office decided that the mechanics should be re-interned, and the factory was closed in January, 1919.

(*f*) NEWALL NATIONAL FACTORY.

The Newall Engineering Company made gauges for the Ministry from September, 1917, on an assisted contract basis, but in the spring of 1918, it became evident that the parent company, Peter Hooker & Co., was using the Newall Works to assist in furthering its own post-war interests, and the output for the Ministry was suffering considerably on that account.[2] It was therefore decided to turn the works into a National Factory. An agreement was made in April, 1918, on the same basis as that with the Wolseley Motor Company. The Ministry was to take over the entire control of the factory, though it was to remain the property of the company. All consumable stores in the factory on 31 January, 1918, the date from which the control of the Ministry was to operate, were to be bought from the Company by the Ministry at actual cost price, plus 10 per cent. for storing and handling. All work in progress for the Ministry was also to be taken over and paid for on the cost plus percentage basis. Admiralty and private contracts then running were to be completed at the discretion of the Ministry, which would receive all payments for such work. From 31 January, 1918, the Ministry was to bear the cost of working and maintaining the factory, taking over the entire staff except the Works' Manager, who was either to be compensated or to be employed elsewhere. As profit the company was to have the sum of £9,000 per annum, beginning from the date of the agreement and payable

[1] 94/G/4986. [2] PM/Misc./384.

quarterly. The Ministry had the option of terminating the agreement at three months' notice, otherwise it was to remain in force for the duration of the war. At the termination of the agreement the company was to have the option of buying, at an agreed price, any additional buildings or plant which might have been erected during the occupation of the factory by the Ministry.[1]

On the signing of the armistice the works were handed back to the Newall Engineering Company, the work in hand, stock, etc., being transferred on the same terms as they had originally been taken over by the Ministry.

(*g*) ASSISTED CONTRACTS.

Another method of increasing output adopted by the Ministry was the assisted contract. Agreements under which the Ministry advanced money for extensions of plant and buildings were entered into with the Coventry Ordnance Works (January, March, May, 1916), Messrs. Tilling Stevens (July, 1916), the Coventry Gauge and Small Tool Company, and Horstmann Cars, Ltd. (July, 1917). The money was either advanced directly by the Ministry, as in the case of Horstmann Cars, Ltd. (50 per cent.),[2] or paid indirectly by means of an increased price for the gauges supplied to the Ministry, *e.g.*, Coventry Ordnance Works (75 per cent.).[3] The difference between these firms and the National Factories was chiefly in the matter of control. The carrying on of the works under an assisted contract scheme was left in the hands of the company, whereas in the National Factories a director was appointed by the Ministry to protect their interests and to co-ordinate the work of the Gauge Department and the factory. Orders were placed on the ordinary contract basis, and though there was no stipulation as to the disposal of the gauges manufactured, in practice the Ministry took the whole output.

(*h*) NATIONAL FACTORIES UNDER LOCAL ADMINISTRATION.

Proposals were also made by the local Boards of Management of Liverpool, Leeds and Birmingham to establish central factories for the supply of gauges to shell makers in the areas under their control. The Liverpool scheme was the most important. The factory which was set up at Bootle[4] made workshop gauges for local requirements, but particularly for the Liverpool National Shell Factory, which formerly made its own gauges.[5] To some extent it was utilised by the Gauge Department for the supply of plain (*i.e.*, not screwed) gauges, both shop and inspection, but on the whole it was found that most of the gauges could be supplied by contractors manufacturing on a much larger scale, and therefore, presumably, at a lower rate. Prices, however, seem to have worked out very reasonably, since, when

[1] PM/Misc./384. [3] 94/G/1367. [2] 94/G/6180; P.M./Misc./384.

[4] The factory was producing gauges in March, 1916, but the exact date at which it was set up has not yet been found.

[5] L.I.B./C/3955/1.

the costs for the first quarter of 1917 were submitted to the Ministry, they were said to compare very reasonably with the costs of other factories.[1]

The Birmingham Gauge Factory was really a department of the National Shell Factory. As early as November, 1915, the Board of Management decided to set up a gauge department of their own, and the shop was equipped and in working order by January, 1916. At first this shop only supplied the needs of the National Shell Factory, but as its output increased it was able to supply also firms in the area controlled by the Birmingham Committee. It has attained an average output of about 200 gauges a week, and since the beginning of 1917 it has, like the Liverpool factory, supplied certain gauges for the Ministry.[2]

The production of gauges in Leeds for local requirements was carried on in the same way as at Birmingham. The Gauge Department of the Ministry had, however, no control over these local enterprises, which were managed entirely by the D.A.O. Department.

IV. Effect of Changes in Design.

The continual alterations in the design of shells and components, especially fuses, inevitably affected the output of gauges and tended to check regular and rapid production. Early in 1916 alterations in the design of the 18 pounder and 4·5 in. H.E. shell caused a temporary decrease in supplies,[3] and in April it was reported that there would probably be a shortage of gauges for the altered marks of 4·5 in., 60 pounder, 8 in., and 9·2 in. shell if a number of makers came on to the new design at once.[4] In May and June the supply of fuse and gaine gauges was somewhat in arrears, because contractors were being put on to the new designs of these components before sufficient time had elapsed for gauges to meet the new requirements to be designed and supplied.[5] The shortage, however, was soon made good, and in general the efforts of the Gauge Department prevented any great delay in output. It was inevitable, however, that there should be a considerable amount of waste, both of labour and of finished gauges. The Gauge Department made every effort to reduce waste by anticipating alterations in requirements, and by promptly stopping work on obsolete gauges and having them converted into new designs; *e.g.*, in January, 1916, Messrs. Cotton & Sons were ordered to convert 100 partially finished gauges for 6 in. shell into gauges for 60 pounder shell, and a number of finished gauges were also issued from the National Physical Laboratory for similar conversion.[6]

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[1] D.A.O./2/1244.

[2] HIST. REC./H/1121-24/6.

[3] (Printed) *Weekly Report*, No. 30 (19 February, 1916), p. 126.

[4] *Ibid.*, No. 39, III. (29 April, 1916).

[5] *Ibid.*, No. 42, III (20 May, 1916); No. 45, III. (10 June, 1916).

[6] 94/G/1551.

Changes in the design of gauges other than those necessary to meet changes in the design of stores had the effect of accelerating production, since their object was always to simplify the work from the gauge manufacturers' point of view. Increased tolerances were sometimes allowed where experience showed that there was a special difficulty in manufacture. Thus in August, 1915, the rejection by the National Physical Laboratory of 50 per cent. of the gauges made for 2 in. trench mortars led to a request for the tolerance to be increased. It was suggested that the gauges might be made to ·001 in., and the Chief Inspector agreed "to do his best to pass the gauges on to Woolwich" with this tolerance.[1] Increased tolerances were also allowed on screw gauges in October, 1915.[2]

In December, 1915, a Committee consisting of manufacturers and representatives of the Ministry was appointed by General Minchin "to deal with and finally determine the best designs of gauges for the purposes required." This Committee originated in a meeting of representatives of the Boards of Management held at the Ministry on November 5 to discuss certain difficulties connected with the supply of munitions. The chief direction in which simplification took place was in the matter of tolerances, the Committee recommending that increases should be allowed in several cases.[3] About 24 February, 1917, a meeting of the Engineering Standards Committee considered the question of the most suitable standards to be adopted for screw-threads, and the gauge contractors to the Ministry were asked to give information as to the most suitable form of thread and the tolerances that should be permitted to gauge-makers.[4]

The Ministry always welcomed any proposals for simplification offered by firms, as, for instance, that of Messrs. Herbert, who, on being asked to tender for gauges for Fuse 84, delayed their quotation in order to take up with the Inspection Department a slight modification in design which would facilitate manufacture and reduce the cost.[5] Gauging devices of different kinds have been invented by many firms to meet needs which have become apparent with the development of new stores. Frequently the introduction of such devices has proved of the greatest value in securing increased accuracy of manufacture or in facilitating rapidity of work.

V. The Testing of Gauges.

Before the war, the testing of gauges for all munitions except rifles took place at Woolwich, where the necessary check gauges were kept. This system was continued until the middle of 1915, when the immensely increased output of all stores, especially gun ammunition and components, made it impossible for Woolwich to cope with the

[1] T.W./B.M./3406. T.W./2767.
[2] (Printed) *Weekly Report*, No. 13 (23 October, 1915), p. 9
[3] Hist. Rec./R/1121/18.
[4] (Printed) *Weekly Report*, No. 81, II. (24 February, 1917).
[5] 94/G/2258.

gauges that came pouring in for testing. When the Ministry of Munitions was formed, new arrangements were made. While some testing still took place at Woolwich, the majority of gauges were diverted to the National Physical Laboratory and tested there. For a few months, while the system of contractors providing their own inspection gauges was in force, some gauges were checked locally, checks being sent from Woolwich when needed ; but when the Gauge Department undertook the supply of all inspection gauges, local checking was no longer necessary, and the work was divided between Woolwich and the National Physical Laboratory, which was in close touch with the Inspection and Supply Departments of the Ministry.[1]

Woolwich continued to deal with gun gauges entirely, and also with gauges for ammunition made by the Ordnance Factories, and for special ammunition only made by two or three contractors. These gauges were to be sent by the makers direct to Woolwich (where the inspection of all special ammunition took place) to be tested and stored there, checks being procured by the Inspection Department from the Royal Laboratory.[2]

All gauges for ammunition in general use, made by a large number of contractors, were sent to the National Physical Laboratory, where they were tested and stored, checks for testing purposes being supplied, whenever possible, by the Gauge Department and kept at the Laboratory. The work which thus fell on the Laboratory was enormous, since the majority of ammunition came into the category of "ammunition in general use." Moreover, as the Department widened its activities to include the supply of gauges for trench warfare ammunition, aircraft, and Admiralty requirements, the testing of these was also put into the hands of the National Physical Laboratory. The organisation of the Laboratory had therefore to be rapidly expanded to meet the demands made upon it. In June, 1915, the staff of the Metrology Department, which dealt with gauges, numbered only five, and the gauges dealt with amounted to about 1,000 a year. Before the end of the year over 50,000 gauges had been tested. This was only rendered possible by a large increase in the staff and appliances. In spite, however, of all the efforts of the staff, the delivery of gauges (at the rate of 600 a day) was in September exceeding the capacity of the Laboratory, and a night shift was put on to deal with the arrears. This, however, was only a temporary expedient, and was discontinued in November, when the congestion was overcome, and the Laboratory settled down to regular work.

During 1916 gauges were being tested at the rate of over 4,000 a week, and this necessitated a further increase of the staff. About February it was decided to experiment with women's labour. This proved very successful as far as the less accurate parts of the work were concerned, and a fair percentage of the staff, which in January, 1918, numbered 200, was composed of women. After the Laboratory took up the increased gauge testing work, the accommodation was

[1] C.R./1250. [2] 94/G/480.

steadily increased, and, besides new buildings for testing, a large new store was erected (July, 1915), in which passed gauges were stocked until they were required by manufacturers.[1] During 1917 the gauges passing through the Laboratory averaged nearly 10,000 a week.

The chief difficulty which the Laboratory experienced was the shortage of check gauges. These were practically unprocurable at first for the new types of inspection gauges. In some cases, *e.g.*, Fuse 100 gauges, the Laboratory made the necessary checks, but for the most part testing was done by direct measurement by means of the standard block gauges made by Messrs. Johansson, of Sweden. Gradually a few firms in England developed the manufacture of check gauges, but the supply was by no means equal to the demand, and much of the testing had to be done by direct measurement.

Most valuable work was done by the Laboratory staff in designing new measuring appliances. This is especially true with regard to the testing of screw gauges. Before the war screw gauges were only being made in England in small quantities by three or four firms, and appliances for testing them were therefore limited. The staff, therefore, turned its energies to inventing new machines, which were then made experimentally in the Laboratory workshops. When the machines were perfected the designs were passed on to specially skilled machine-tool makers, who turned out machines for the Laboratory and also for gauge-making firms. A certain number of the machines required for their own use were still, however, made by the Laboratory staff, and experiments in the production of standard block gauges of the Johansson type were in progress at the end of 1917.

As regards the passing of gauges, the Laboratory experienced the greatest difficulty with screw gauges, and especially profile gauges, or those which test the shape of the thread. At first the numbers sent in were small and the percentage of rejections high. During the last five months of 1915 49·7 per cent. of screw gauges were passed as compared with 75 per cent. of general gauges. A steady improvement, however, took place, both in quantity and quality. In 1916, 64·4 per cent. and in 1917, 68·3 per cent. of screw gauges were passed, while the percentage of general gauges remained fairly steady. The quality of screw gauges, however, improved in a greater ratio than is indicated by these figures, as the rigidity of inspection, due to improved methods of measurement, kept down the percentage of passes.

Besides storing and testing gauges the National Physical Laboratory gave invaluable assistance to the Gauge Department by helping manufacturers to overcome their initial difficulties. Advice as to methods of manufacture was given by the Laboratory staff, and demonstrators were sent out to manufacturers' works if necessary. The Laboratory also arranged to test manufacturers' gauges when desired.[2]

[1] C.R./971. [2] HIST. REC./R/1121/23.

Rifle gauges did not fall within the purview either of Woolwich or the National Physical Laboratory, being tested and stored at Enfield.

VI. Conclusion.

The partial cessation of the manufacture of munitions which followed the signing of the Armistice was naturally accompanied by a similar curtailment of gauge manufacture. Contractors were notified by the Gauge Department that, generally speaking, orders would cease immediately, and that they would be required to complete outstanding orders or to deliver the unfinished gauges to the N.P.L. as soon as possible. In many cases contracts were concluded by mutual agreement, and in others by the operation of the break clause. Screw gauge manufacturers who had contracts for aeroplane gauges were allowed to continue, as the demands of the Air Department were not considerably affected by the Armistice. As has been said, arrangements were made for the return of the National Gauge Factories to private ownership as soon as possible. It was expected that most of the firms concerned would return to their normal business if that had been interfered with, though possibly both the Vidal Engineering Company and Messrs. Pitters would continue high-class gauge-making.

The developments which took place in gauge manufacture under the direction of the Ministry between 1915 and 1918 will probably have a marked effect on the future of the industry. With the aid of the Gauge Department many firms succeeded in equipping their factories with suitable plant, and organising their industry on a firm basis. The extended use of limit gauges, which has been such a marked feature in the engineering trade during the war, seems likely to continue, and this will create a demand, which will enable these firms to carry on a business thus successfully developed. Very valuable experience has also been gained with regard to the importance of a steady supply of machinery of simplified design, the part that can be played in gauge manufacture by repetition work, and the value of simplicity in design in promoting rapidity of output and economy of production. If the experience thus gained and the organisation built up through the exigencies of war can be utilised in the period of reconstruction following the war, there seems no reason why a flourishing gauge industry should not be established, which will help to absorb the labour released from the Army, and place the supply of gauges, which, before the war, was largely in the hands of foreign countries, under the control of home manufacturers.

CHAPTER II.

MACHINE TOOLS, SMALL TOOLS AND CRANES.

I. Introduction.

The manufacture of machine tools is not, in one sense of the word, a primary industry in relation to war. That is to say, machine tools do not, like guns, shells and explosives, play an immediate part in the field. But in so far as these and all other munitions cannot be produced in the quantities required by modern methods of warfare without the use of highly complicated machinery, machine tool manufacture may be rightly termed a key industry. At the outbreak of war, this fact was not fully recognised either by the workman, who tended to leave the industry for service in the army or for the direct production of war material, or by those responsible for the output of munitions, and no immediate steps were taken to organise the industry for war production. Experience, however, rapidly corrected this mistake. Leaders of the industry were the first to realise the danger of neglect, and drew the attention of the Government to the need for investigating the potentialities of the trade. Once set on foot, the organisation for the control and distribution of machine tools rapidly expanded under pressure of the increasing demand, and during the whole period of the war it formed one of the most important of the Government activities.

(*a*) Definition of Terms.

Machine tools can best be defined in general terms as "power-driven machines for cutting, working, or abrading metal." The original machine tool was the lathe, the modern commercial development of the potter's wheel. The lathe in its different forms is still the principal machine tool used in every industry, but by its side modern invention has placed milling machines, planing, shaping and slotting machines, boring and grinding machines, automatic screw machines and various other tools designed to promote rapid and efficient output. All these machines are made in different forms and sizes according to the use to which they are to be put. For the production of artillery, for marine engineering and shipbuilding, machines of the heaviest description and largest dimensions are necessary; at the other end of the scale there is the light machinery required to make rifles, cycles, sewing machines, watches, optical instruments, and other delicate articles. Between these two extremes lie infinite possibilities as regards size and form, and a definition which is general enough to cover all the varieties of machine tools and yet simple enough to appeal to the non-technical mind is not easy to find.

Wood-working machinery, though closely allied in principle to metal-working machinery, obviously does not fall within the limited definition given above. In attempting to control the machine tool trade it was, however, found that wood-working machinery must be dealt with also. For the immediate purpose, therefore, the scope of the term " machine tool " may be widened to embrace both metal-working and wood-working machinery.

The small tool is so closely connected with the machine tool that one is useless without the other. Different machine tools require different small tools such as chucks, arbors, cutters, drills, reamers, taps, dies, jigs and fixtures, according to the function they have to perform. The small tools, generally speaking, do the actual work of shaping and cutting to the dimensions required, while the machine tool is the medium through which movement and direction are given to the smaller implement. The greater wear and tear thus falls on the small tool and necessitates its frequent replacement. It is therefore necessary to have an adequate supply of small tools with which to equip a machine if it is to be kept working at its maximum capacity, and one of the most obvious lessons driven home by the war was the need of greatly increased facilities for the manufacture of small tools. Although not actually used for cutting, many measuring and gauging appliances are included under the heading of small tools.

Machine tools play an indispensable part in modern industry, for production on any scale at all is impossible without them. The old method of manufacture, in which the individual craftsman worked at an article in all its stages from the rough shape to the finished form, has been replaced by the co-operation of a number of people, each of whom specialises in one operation only on large numbers of articles which are turned out in quantities by repetitive methods. The parts are then assembled to produce the finished article. But in order that the parts may fit one another when assembled they must be accurate within limits extending in many cases to considerably less than a thousandth of an inch. Such accuracy cannot be secured by hand labour without a high degree of skill and a large expenditure of time. A machine tool, on the other hand, can be made to turn out uniform articles to any reasonable limits as long as it is maintained in sound condition. If, therefore, the attention of the skilled workman is concentrated on the production of an accurate machine tool, semi-skilled labour can be used to operate it without detriment to the quality of the article to be produced. The value of machinery in securing rapidity and economy of output is obvious, while its accuracy is such that even the most delicate mechanism, as, for instance, that of the modern rifle, can be produced far more efficiently than by hand labour. In a crisis such as war, output on the scale of war requirements can only be achieved by the intensive use of mechanical devices of every description, and an adequate supply of machine and small tools is therefore a *sine qua non* for military success. Thus it was necessary during the war to pass outside the area of munitions in the strict sense of the word and to organise for war purposes an industry which was already existing as an essential part of our normal industrial organisation

The achievement of the Ministry of Munitions with regard to machine tools was not the creation of a new industry; it was rather the stimulation and remodelling of an old industry to meet new and abnormal conditions.

(*b*) The Machine Tool Industry at the Outbreak of War.

At the outbreak of war the machine and small tool industry in Great Britain was in the hands of three classes of traders:—(*a*) the manufacturer; (*b*) the merchant; (*c*) the importer.

These divisions were not, however, mutually exclusive; for the development of the industry was tending towards making the merchant also a manufacturer, while the manufacturer often added to his activities the further functions of merchant and importer.

Machine tool manufacture in Great Britain was, broadly speaking, grouped in four districts, where the demand for machine tools was great on account of the industries of which these districts were the centre. Lancashire was the early home of the machine tool trade, and at one time had the reputation of producing the best quality tools. Yorkshire competed closely in quantity of output, but the machinery was, with some exceptions, of a lower grade, being simpler in design and produced by a number of small makers who had not the organisation and the up-to-date methods of the larger trades. The Midlands produced, on the whole, large numbers of machines of the type required for repetition work and suitable for use in the small arms, motor and cycle trades, while the shipbuilding and marine engineering industries of the Clyde had resulted in the development of a flourishing industry in machine tools of the heavier type in the immediate neighbourhood.

With certain outstanding exceptions, the general tendency of the British machine tool maker was conservative both as regards novelty in design and quantity of output. Most machine tool makers built simply to order, each firm producing in small numbers machines of the designs required by its customers. This lack of specialisation, combined with lack of enterprise in building for stock, tended to limit the trade of British machine tool makers, though for strength and durability the British machine tool had a reputation second to none on the market. American competition was, however, steadily eliminating these faults of too great caution and uneconomical methods of production, and immediately before the war makers were developing the methods of specialising in a certain type of machine, and building for stock, and therefore adopting a more active commercial policy abroad as well as at home. Not only did British products hold the field at home as far as certain classes of machinery were concerned, but they were exported to every country in the world except the United States, which had a prohibitive tariff, and they competed with advantage in foreign markets with the productions of America and Germany, the only other countries with a considerable machine tool industry.

The developments in the industry contributed to the growth of the merchant business. The merchant often began as a second-hand machinery dealer ; then he extended his business by acting as middleman for the small maker, often financing him and making it possible for him to increase his manufacture. During the years immediately before the war there was a marked tendency for the merchant to extend his operations to the better types of machinery, while the export trade was largely in his hands. In many cases it was the practice of the merchant to undertake to furnish a large plant for the manufacture of a particular article, procuring the necessary tools from many different makers.

The third class of trader, the importer, played a large part in the organisation of the whole industry. The two principal countries from which machines were imported before the war were America and Germany. Of the two, the former was by far the more important, and as, automatically, importation from Germany ceased on the outbreak of war, America became to all practical purposes our sole source of foreign supply. The American output of machine tools was large owing to the fact that a prohibitive tariff secured to her an enormous home market, while she was also free to enter the markets of other countries. American makers could thus build in large quantities for stock, and this, combined with their specialised and progressive business methods, enabled them to produce cheaply and efficiently in spite of high wages, and to capture the markets of other countries to a large extent. As a rule, American machine tools were imported into the United Kingdom by firms within this country, who established themselves as general American importers. As these firms increased in number they developed a tendency to specialisation. Each firm secured sole agencies for a certain number of American manufacturers, who assisted them by sending trained demonstrators over to work the machines and to advertise their advantages. Immediately before the war, the importing industry formed a large part of the machine tool trade in Great Britain, especially as regards machine tools of the lighter type and small tools, for the supply of which we were in many cases almost entirely dependent on American enterprise.

Thus at the outbreak of war there was a steady supply of machine tools in Great Britain to meet the normal demand, and the tendency was for this supply to increase as new industries developed, and labour-saving machinery usurped the domain of skilled labour. As in most other industries, the effect of the war was to produce a temporary paralysis. The demands of the arsenals, the dockyards, and the armament firms only increased very gradually at first, while other contracts were cancelled, for the financial uncertainty of the early days of war acted as a check on enterprise. Matters, however, adjusted themselves after a month or six weeks, and as the demand for munitions went up by leaps and bounds, the pressure on the machine tool trade became enormous. It became obvious that the existing resources of the trade, hampered as it was by increasing scarcity of labour and material, would not be sufficient to meet the demands unless

much greater output could be secured by improved organisation and proper distribution. The matter was taken up as a question of national importance in the spring of 1915, and the first steps were taken by the Government towards a system of control which eventually became as widely spread and as rigidly enforced as that applied to any other industry in the United Kingdom.[1]

II. Organisation of the Machine Tool Department.

(a) Headquarters Organisation.

The first movement towards organisation came from within the trade itself. In March, 1915, Mr. Alfred Herbert, who, as Chairman of the Machine Tool Association (which included in its membership the majority of the leading manufacturers, merchants and importers) and head of one of the largest machine tool firms in the kingdom, had unique opportunities of knowing the state of the trade, wrote to Sir Arthur Lawton, the Chairman of the Engineering Employers' Federation, and to Mr. Lloyd George, then Chancellor of the Exchequer, making suggestions as to how the existing chaos might be straightened out and a better distribution of output secured. The result was that in April Sir Percy Girouard asked Mr. Herbert to undertake the organisation of the machine tool trade. On 27 April the department began operations on a small scale at the Cecil Chambers as a department of the War Office. For about two months it worked thus with very nebulous powers; then, on the establishment of the Ministry of Munitions in June, 1915, it was transferred to Armament Buildings, and systematically organised as part of the Ministry.

It is impossible to describe in detail the organisation at Armament Buildings. There are, however, certain landmarks in the growth of its personnel and functions which can be recorded. At first no differentiation was made between machine and small tools, but as the small tool problem developed it became necessary to deal with it on special lines, and in September, 1915, a Small Tool Section was organised in the department. In March, 1916, the extension of control to lifting and conveying appliances brought into being the Crane Section, while the difficulty in obtaining raw materials resulted in September, 1916, in the establishment of the Stamping and Casting Section. This last appears, however, to have been in the nature of an anomaly within the Machine Tool Department, and was transferred to the Steel Group at the end of 1917.[2] On the other hand, the work of the department was considerably increased by the control of prices, which necessitated the formation of a Prices Section, and by the transference to the department in September, 1918, of the work of the Central Clearing House with regard to the release of machine tools.[3] At the signing of the Armistice the department was organised as a

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[1] See History of the Machine Tool Department, Part I., by Sir Alfred Herbert. (Hist. Rec./H/1700/1.)

[2] See below p. 55.

[3] See below p. 45.

complete unit under the Controller, Mr. Edward M. Iliffe, who had succeeded Sir Alfred Herbert in April, 1918, in seven sections (T.M. 1-7), dealing respectively with the supply of machine tools, prices, small tools, cranes, control, investigations and releases. Complete arrangements were also made for the department to take over machine tool stores and accounts from the Central Stores Department, but upon the signing of the Armistice this was abandoned.

The Machine Tool Department was organised at the beginning by voluntary workers, and the men responsible for the direction of its policy throughout the war served, in nearly all cases, entirely without remuneration. Among these may be specially mentioned Sir Alfred Herbert, the first Controller, and Mr. Edward M. Iliffe, who succeeded him, and who was attached to the department for over four years. Mr. P. V. Vernon placed his wide technical experience unreservedly at the disposal of the Ministry, and his services in this respect as well as his administrative work as Assistant Controller proved invaluable to the department. Another valuable voluntary worker was Mr. J. D. Steven, the head of the Small Tool Section. The debt that the Ministry owed to these and other workers was all the greater in that the successful establishment and working of the Machine Tool Department depended largely on the possession of expert knowledge of machine tools and the machine tool trade. In 1915 men with such knowledge could hardly have been secured by ordinary business methods. It was therefore only by voluntary assistance that the department was able to carry on its work, and to keep that close connection and cordial co-operation with the trade in which the secret of its success is very largely to be found.

(*b*) ADVISORY COMMITTEES.

As the increasing activity of the department entailed more and more interference with the trade, it was felt desirable to secure the co-operation and advice of the leading machine tool makers who would act for the whole trade in protecting its legitimate interests and securing its acceptance of the necessary control. The formation of a committee of the trade had been a leading feature of Mr. Herbert's early suggestions, and in July, 1915, the idea was again put forward by Mr. Lloyd George, at a conference with the leading manufacturers, as the best means of administering control. Accordingly a voluntary Advisory Committee of six was appointed by the Minister of Munitions, Government appointment rather than election being the method decided upon by the makers themselves. In addition to the Chairman, Mr. Herbert, there was a representative from each of the four principal manufacturing districts and a representative of the importing firms. Additions were made at intervals during the lifetime of the committee. In September, 1915, the Director of the newly formed Small Tool Section, Mr. J. D. Steven, was elected. In December, 1916, Mr. Iliffe, Assistant Director of the Machine Tool Department, became a member, and two members were added to represent the Finance and Contracts Departments respectively in order to obtain closer co-operation between

the several departments. Early in 1917 a representative of the wood-working machinery trades was elected, and in February, 1918, the Director of the Prices Section, Mr. J. W. Milne, was also appointed to the committee.[1]

In July, 1917, a Sub-Committee was appointed to advise the Machine Tool Committee with regard to applications by individual firms for permission to increase their prices. It consisted of those members of the committee who were not members either of the machine tool or wood-working machinery trades, together with a representative of the Controlled Establishments Division. Mr. Edward M. Iliffe acted as Chairman. Practically all questions relating to prices were dealt with by this sub-committee, whose recommendations were formally confirmed by the Machine Tool Advisory Committee.

In the autumn of 1918 a second advisory committee was constituted, on lines similar to the Machine Tool Committee, to deal with small tools. The limitation of merchants' and importers' profits on small tools during 1917, and the control of manufacturers' prices early in 1918, evoked a general demand for such a committee. The first meeting of the Small Tools Advisory Committee was held in September. It consisted of eight representatives of the small tool trade and six Ministry officials, most of whom were already serving on the Machine Tool Committee.[2] Owing to the signing of the Armistice in November, the actual work done by the committee was comparatively little, but had the war continued there can be little doubt that it would have proved to the department as valuable a link with the small tool makers as the Machine Tool Committee already was with the machine tool trade.

In September, 1918, also, a Merchants' and Importers' Panel was set up, because the merchants and importers felt that their interests were not sufficiently safeguarded by the Machine Tool Advisory Committee. Its personnel consisted of eleven members representing the trade and five Ministry officials representing the Machine Tool and Contracts Departments,[3] and its functions were to advise the department on matters connected with the sale and importation of machine and small tools.

(c) Local Organisation.

The increasing control of the trade necessitated a considerable amount of local organisation by the Machine Tool Department, some of which was permanent, some merely temporary, to meet special difficulties. The chief permanent organisation was the staff of inspectors and supervisors. The first travelling inspectors were appointed in September, 1915, and as their work was extended and its value proved, their numbers were increased considerably. Their primary object was to accelerate production by advising manufacturers

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[1] Appendix V. [2] *Ibid.* [3] *Ibid.*

in their difficulties, assisting them to obtain supplies of raw material, suggesting simplification of processes, and generally smoothing the path wherever possible. They also advised the department as to available capacity and when deliveries might be expected; they investigated costs and saw that firms complied with the regulations regarding the trade. In the case of most firms visits at intervals were sufficient to ensure this last, but in certain instances where evasion of regulations was deliberate and repeated, it was found necessary to appoint resident supervisors. During 1916 and 1917 supervisors were appointed by the department to at least five firms.[1] The withdrawal of permits to trade was, however, a more common measure with recalcitrant firms.

Temporary local organisation is found in the measures taken to deal with congestion at the ports. In the early days of the Ministry the volume of importation from America was necessarily large and the result was great congestion at the ports, especially Liverpool. The Machine Tool Department soon found that even when the tools ordered arrived in England, they could not be put into use quickly on this account, so an official was appointed to deal with the situation at Liverpool, Manchester, and London. The result of this move was that machines previously delayed at the ports for five or six weeks were put on rail within a few days of their arrival. So successful was the procedure that the services of this official were requisitioned by other departments, his work was extended to include steel and other materials, and increased in this direction to such an extent that it was considered advisable to transfer the work to the Steel Department, and thereafter, as an offshoot of the Machine Tool Department, it ceased to exist.

Another organisation with a similar history was the mission to America of Mr. Searle and Lieut. Lang in the autumn of 1915. Originally sent out by the Machine Tool Department to induce American manufacturers to ship a larger proportion of their output to England, they extended their operations to the direct purchase in the States, through the agency of Messrs. Pierpont Morgan & Co., of large quantities of machine tools (particularly for heavy shell) and to encouraging general engineering firms to take machine tool contracts with the assistance of drawings and designs supplied by British firms. Eventually this mission was absorbed in Sir Ernest Moir's organisation in the United States, and its work for the Machine Tool Department thus became part of a larger whole.

(*d*) Relations with other Departments.

The work of the Machine Tool Department necessarily involved considerable relations with the Supply Departments of the Ministry,

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[1] These firms were Messrs. Haigh, Gruban & Co., Ltd., and Messrs. J. Whiteley and Son, Ltd., March, 1916; Messrs. Ward, Haggas & Smith, Ltd., October, 1916; The Centaur Tool Works, Ltd., and Messrs. J. R. Kelly & Co., Ltd., June, 1917.

whose ability to meet the demands of the War Office depended to a large extent upon a sufficient supply of machine tools to their contracting firms and upon the proper equipment of national factories. It also involved relations with other Government Departments, such as the Admiralty, the Air Board, and the War Office, from whom there came a considerable demand for machine tools. As Sir Alfred Herbert expressed it, the Machine Tool Department was the "servant of all the other Departments," a position in which it was apt to get more kicks than halfpence. Each Supply Department naturally urged its own particular claims to assistance, and as, generally, no definite guidance was forthcoming in this respect, the department had itself to take the responsibility of adjusting rival claims. At a later stage, however, the War Priorities Committee was set up, and a Machine Tool Sub-Committee was formed, under the chairmanship of the Controller of the Machine Tool Department, to perform this onerous duty.

With the Raw Materials Department, the Labour Supply Department and the Priority Department, the Machine Tool Department was always in close touch, in order to assist manufacturers to fulfil their orders as quickly as possible. Relations with the Finance Department were slight compared with those of other departments, since the expedients of giving financial assistance to firms and setting up government factories were never adopted to any great extent. With the Contracts Department also the connection was not at first close, since the department avoided placing direct Ministry contracts as far as possible ; but this policy had to be modified later under pressure of necessity, especially when the limitation of American supplies in 1918 forced the department to open up new sources of supply at home, and to take the responsibility for making good the deficiency. The placing of direct Ministry contracts then became much more common, and the connection with the Contracts Department correspondingly closer. Ultimately the Director of the Prices Section of the Machine Tool Department was also appointed Director of those sections of the Contracts Department (C.E.6 and C.E.7) which dealt with the placing of contracts for machine tools ; and, as has been seen, a representative of the Contracts Department was appointed to act on the different advisory committees of the Machine Tool Department.

With the Central Clearing House[1] the Machine Tool Department naturally worked in close conjunction, since both dealt with the supply and distribution of machine tools. Contractors wishing to order new machine tools applied to the Clearing House authorities for release certificates to enable them to place their orders, while the firms receiving the orders applied to the Machine Tool Department for permission to supply the machinery required. The Central Clearing House also obtained particulars of available second-hand machinery capable of being transferred to firms requiring similar machinery for war

[1] For a full account of the Clearing House system, see Vol. VIII., Part IV., Chapter I.

work, such information being supplied by them to the Machine Tool Department. It was, therefore, absolutely essential that there should be close co-operation between the two departments if friction and delay were to be avoided. In spite of the efforts of both departments, the delay experienced in obtaining machine tools was a ground for increasing complaint by all firms in 1917 and 1918, and ultimately it was decided that the work done by the Clearing House authorities with regard to machine tools was really part of the work of the Machine Tool Department. In September, 1918, the release of machine tools was handed over to the department, and the necessity for its close connection with the Central Clearing House ceased to exist.[1]

III. Work of the Department.

The phrase "control of metal and wood-working machinery" only indicates very broadly the work of the Machine Tool Department. To appreciate to the full its many-sided activity more detail is needed. Since machine and small tools of various kinds are used in practically every industry, the allocation of output among the numerous manufacturers clamouring for tools alone involved a vast amount of work, as well as tact and discrimination; and when the control of prices was added, supervision of private industry became minute in its detail. In addition, all the requirements of Government Departments, including the Supply Departments of the Ministry, were referred to the Machine Tool Department for advice and approval; and much valuable technical advice was given by the experts on the staff of the department. As the practice of arranging assisted contracts found favour, and the number of national factories increased, this side of the department's work grew very rapidly.

The section of the department over which Mr. P. V. Vernon presided undertook a great deal of work in this connection, as well as in connection with the provision of machines for shell manufacture to private contractors, for which at the time no other machinery existed. Boards of Management and contractors would visit the Ministry with the general idea that they were to make shells, but without the vestige of a notion as to how to set about it, and it devolved upon Mr. Vernon and his staff to instruct them in the minutiæ of shell manufacture. A list of operations with the estimated times would be prepared; advice as to suitable machines to perform the operations would be given; cutting speeds gone into; the arrangement of the machinery and the floor space required discussed; and in fact everything possible would be done to facilitate production at the earliest possible moment. At a later date this work was taken over by the

[1] See History of the Machine Tool Department, Part II., by Sir A. Herbert (HIST. REC./H/1700/1); Memorandum on the Constitution and Functions of the Machine Tool Department at November 11, 1918, by Mr. E. M. Iliffe (HIST. REC./R/263/23); Central Clearing House (HIST. REC./R/1710/1 and 1710/2); Minutes of the Machine Tool Advisory Committee, the Merchants and Importers' Advisory Panel and the Small Tool Committee; Deputation of Members of the Machine Tool and Engineering Association (D.D.G.T./921).

Shell Department, but until the latter was fully organised and possessed of a staff capable of undertaking this detail work, it continued to devolve upon the Machine Tool Department. Mr. Vernon's section also performed similar functions in connection with the gun-relining programme, which at the time was a matter of first-class urgency; and Mr. F. E. Bagnall undertook, with marked success, similar duties in regard to the manufacture of other munitions.

Naval and aerial developments also involved the department in greatly increased activity, since the Admiralty required assistance in obtaining machinery to produce mines, mine-sinkers and other devices for submarine warfare; and the demands of the Aircraft Department increased as their programme of construction was extended. Besides manufacturing activity, the department had to supervise the steadily increasing volume of importation, while the necessity of supplying our Allies involved it in questions of export also. The control of lifting machinery, though narrower in its range and less intricate in its problems, required the collection of a large amount of information and the establishment of relations with an increasing number of firms. Difficulties in the supply of material also involved for a time a measure of control over forgings and castings.

Had the department attempted to supply directly all the many requirements of contractors, Government Departments and Allies, it would have been overwhelmed by the mass of demands made upon it; and from the outset, therefore, it adopted the policy of bringing machine tool firms into relation with the contractors or departments requiring supplies, and limiting its functions to advice and approval. It was, however, impossible to carry out this policy rigidly during the whole of the war; and in certain directions, particularly with regard to small tools, and at certain periods when demand was particularly heavy, the department was forced to add to its work by entering into direct contracts both with British and American makers, and by arranging output in government factories or on an assisted contract basis; but such activity was the exception rather than the rule, and in contrast to most departments of the Ministry the amount of direct supply arranged by the Machine Tool Department was comparatively limited.

Another development of the department's work was the distribution of second-hand machinery. The sources of supply were so inadequate to meet the demand that at an early date it became a matter of primary importance to register all idle machines and transfer them to firms requiring them, instead of sanctioning orders for new ones. This side of the department's work was at one period undertaken in conjunction with the Central Clearing House, but was ultimately taken over entirely by the Machine Tool Department. Thus, in 1918 the surveillance of all the machinery at work or in progress of manufacture in the country, together with the control of that coming in or going out, fell within the sphere of the Machine Tool Department, and only the most careful organisation, both locally and at headquarters, enabled the volume of work which this entailed to be dealt with successfully.

(a) CONTROL OF BRITISH MANUFACTURERS OF MACHINE TOOLS.

When the Machine Tool Department was set up, there was so little knowledge of the trade at hand that not even a complete list of machine tool builders existed. In March, 1915, a census of machine tools in use in the engineering works throughout the country had been taken by the Factory Inspectors, but, beyond showing that only about 50 per cent. were engaged on government work, this census had prove . of no value. The first thing, therefore, which the department did was to make as complete a list as possible of the machine tool firms in the country, with details of their specialities in manufacture. Armed with this and the facts elicited by the Home Office census, the department endeavoured to introduce some sort of order and co-operation into the trade, and to direct the flow of work into channels where manufacturing capacity was immediately available. Under Regulation 8A of the Defence of the Realm Act, giving the Army Council general powers of direction, limitation, and regulation of manufacturers' output, a circular was issued to the trade in May, 1915,[1] directing manufacturers to classify their orders into Class A—British and Allied Government orders and contractors' orders for machinery for munition work; and Class B—orders from neutral countries and non-munition contracts. Preference was always to be given to Class A work. Detailed information was required as to export orders and orders for civil work, and the department used its discretion as to diversion of the work begun for these to other purposes. The question of orders for neutrals was most important, as there was evidence to show that many of the machines under these contracts were destined for German use. By these measures a great deal was done to direct the existing capacity in the country into the right channels, a course which was all the more necessary as the demands of the great armament contractors became more and more urgent, and the setting up of the National Shell Factories entailed a heavy demand for equipment. Some help in meeting this demand was obtained in June by the diversion of a number of machines from intercepted cargoes from the United States to Scandinavia. These were seized, and the greater part of the machinery was distributed for use in the United Kingdom. Such a course, however, could only afford temporary relief, and the real remedy for the evils of delay in output lay in getting as much production as possible from the manufacturers. To this end officials from the department visited all the firms in the country giving advice and assistance in the obtaining of raw materials, indicating order of precedence in the matter of contracts, and generally affording whatever assistance was possible to the harassed and overworked makers.

Such control as was exercised under the Order of May, 1915, was only general, and dependent for its success to a very great extent on the goodwill of the individual manufacturer. When the Machine Tool Department was transferred from the War Office to the Ministry of Munitions, it was decided to institute a more definite system of control. A circular was issued to the trade on 16 July, 1915, stating

[1] Appendix VI.

that henceforward the machine tool trade would be controlled under the Munitions of War Act, and that a committee would shortly be appointed to confer as to the best means of administering control. This was the Machine Tool Advisory Committee, which played such an important part in the whole scheme of control.[1] This was followed by another circular, stating that all orders for machine tools were to be submitted to the department, and no orders were to be accepted without the sanction of the department, unless they were given by certain of the Supply Departments of the Ministry, the Admiralty, or the Army Council.[2] The system of sanctioning thus instituted formed the basis of the whole system of control. By the submission of orders the department gained detailed knowledge of the types of machines required, while by refusing sanction they were able to eliminate civil and commercial work in a systematic fashion and concentrate firms' efforts on machines essential for war work.

A census of orders taken in July, 1915, showed that on an average firms were booked up for the next six months. At the same time the inception of the scheme of National Projectile Factories threw upon the department the responsibility of arranging for the large amount of machinery necessary for their equipment. This brought the department face to face with the problem of extension of output. So far they had been occupied with organising the existing sources of supply in order to gain the maximum output, but it was obvious that existing sources could not possibly meet the new demand. There were four possibilities of extension :—National Machine Tool Factories, similar to the National Shell and Projectile Factories ; assisted contracts on the same lines as those already arranged for shell production ; financial assistance to firms to enable them to undertake extensions ; and sub-contracting. As the policy of the department was not to undertake supply itself except as a last resource, the first two expedients were not adopted, the third was only sparingly used, and the department relied chiefly on the extension of sub-contracting to provide the increased output necessary.[3] Machine tool manufacturers were encouraged to sub-contract to general engineering firms who had available capacity, and to allied industries, such as printing machinery firms, and the department rendered all assistance possible by collecting information as to such facilities and communicating it to the trade, and by sending inspectors and officials to give advice and help to firms undertaking such work when required. Many difficulties of detail inevitably arose from this sub-contracting system, such as the use of drawings and patterns, the question of whether a sub-contractor to a certain manufacturer should be allowed to take work from other manufacturers as well, and whether contractors might legitimately place speculative orders with sub-contractors. The general policy of the department appears to have been to interfere as little as possible between contractor and sub-contractor and to leave the sphere and the activity

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[1] See above p. 41.
[2] Appendix VII.
[3] This refers to machine tools only. With regard to small tools, a limited amount of Government activity was necessary (see below p. 52).

of the sub-contractor as free as possible. An inevitable result of the sub-contracting system at first was the inferiority of many of the machines produced, but this defect was remedied to some extent by time and experience. On the whole the sub-contracting method appears to have worked well and was very largely employed during the whole period of the war.

Financial assistance to firms was a second string, but was a policy adopted with considerable caution. In September, 1915, a Birmingham firm asked for financial support in the form of the Government holding of debentures in their firm, and was told that the Machine Tool Committee were unable to recommend the Government to undertake financial responsibility at that date. This policy was generally adhered to throughout the war, though in 1918 the necessity for replacing the dwindling American supplies by home manufactures led to its modification being considered, but not acted upon.

The application to the machine tool trade in August, 1916, of Regulation 30A of the Defence of the Realm Act, which prohibited firms from trading without a permit, was primarily in the interests of price control, and will therefore be dealt with in that connection.[1]

The next tightening of control came early in 1918 when the effect of America's entry into the war began to be felt. The limitation of export which this entailed made it necessary to make good the deficiency by home manufacture. Accordingly the department began to apply systematically a procedure which formerly had been only tentative, the policy of concentrating certain manufacturers on certain types of machines entirely. Manufacturers were asked to submit their manufacturing programmes to the department and these were then adjusted and rearranged. Firms who were best equipped for the production of a standard machine were told to concentrate on those machines. Firms whose programmes showed a dissipation of energy over a variety of different types of machines were instructed to cut down their proposals to a few types in the production of which they had already proved their capability, and all firms were asked not to manufacture any articles other than machine tools if these conflicted with the output of machine tools. This was very necessary, as many machine tool makers were tempted to undertake other work, such as parts for aeroplane engines, which would have enabled them to earn a higher rate of profit than they were allowed to make on machine tools.

The Armistice intervened before the real result of this policy could be seen, but there were indications even at that time that it would have produced a still greater increase in output, and 1919 would have seen the greatest possible use being made of the existing facilities, and the maximum output attainable by organisation without extension being secured.

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[1] See below p. 60.

(b) Control of Importation of Machine Tools.

In spite of the increase in home manufacture, importation played a large part in the supply of machine tools throughout the war. Certain types of machines were not manufactured at all in Great Britain, and British industry needed supplementing wherever possible because of the enormous demand. The majority of imported machines came from America. Some were obtained from Spain and Switzerland, but there were such difficulties with the supply of raw materials, all of which had to be sent from Great Britain, and so much delay in delivery that little reliance could be placed on these sources of supply. Moreover the prices were quite uncommercial and almost prohibitive. From America there was a steady flow of machinery into the country, in spite of the transit difficulties experienced. Besides the temporary congestion at the ports, due to the sudden activity of the importers following the outbreak of war, there was the possibility of the destruction of large consignments of tools by enemy action at sea. This was brought home very forcibly to the authorities by the sinking of s.s. "Cymric" with 1,387 cases of machine tools on board. Such disasters were, fortunately, comparatively few, and once the initial difficulties were surmounted, the system worked as satisfactorily as could be expected in view of the increasing requirements for the transit of all kinds of munitions and the decreasing number of ships available.

The acceleration in demand owing to the establishment of the National Projectile Factories led to attempts to get a larger proportion of American machinery exported to Great Britain, and then to get an expanded output in the States. The principle adopted at home of encouraging general engineering firms to undertake the work was applied in the States through the agency of Mr. Searle and Lieut. Lang.[1] In this lay the only possibility of expansion, since in the autumn of 1915 American machine tool firms were overwhelmed with orders, and were in addition involved in labour difficulties. The success of the policy may be judged from the fact that orders to the extent of £1,000,000 were placed through Messrs. J. P. Morgan; but there must also be reckoned the very considerable drawbacks in the relative inferiority of many of the machines, both in materials and workmanship, as well as the uncertainty of delivery. The former defects were to some extent overcome by the organisation of a system of inspection in the States. To deal with the latter, cancellation clauses were inserted in the contracts; but it was not often necessary to put them into force, since the demand was so great that, however late in delivery, a use could be found for the machines.

In November, 1915, a Proclamation was issued prohibiting the importation of machine tools except under licence of the Board of Trade.[2] Like the permit system with regard to manufacture, this was designed to control prices, not to limit supply. Limitation of importation became, however, inevitable in the autumn of 1917

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[1] See above p. 43. [2] Appendix VIII.

because of America's own needs. In February, 1918, the Minister stated that it was advisable to reduce the importation of American machines to the absolute minimum. Arrangements for the manufacture at home of machines hitherto imported were made by the department, but the difficulties in the way were considerable, since the regular machine tool firms were already fully occupied, and the novelty of many of the designs required made less experienced firms chary of undertaking the work. Judging by the figures of importation for 1918,[1] which show no appreciable decrease during the year, the effect of any arrangements made were not felt before the signing of the Armistice. Probably, however, they would have resulted in a considerable alteration in the proportion of imported supply to home manufacture during 1919.

(c) CONTROL OF WOOD-WORKING MACHINERY.

The control of wood-working machinery was not imposed till comparatively late in point of time. In May, 1917, owing to the growing demand for machinery for aeroplane construction and to the fact that controlled machine tool firms were penalised as against uncontrolled wood-working machinery firms, there arose a strong demand for the extension of control to include wood-working machinery. The result was that in June an order was issued placing such machinery under Regulation 30A of the Defence of the Realm Act.[2] The system of permits to manufacturers and licences for importation, together with their correlative, the control of prices, was thus extended to wood-working machinery.

(d) CONTROL OF SMALL TOOLS.

The problem of the supply of small tools was one of the earliest the department had to face, and it was complicated by the fact that the number of small tool makers in the United Kingdom was comparatively limited, while the demand was relatively large owing to the wear and tear to which small tools were subjected. The first step taken by the Small Tool Section, over which Mr. J. D. Steven ably presided, was the formation of a list of small tool manufacturers with particulars of their output. This was then compared with the information as to requirements obtained from the largest users, including various Government Departments. The result showed there was likely to be a considerable shortage. Steps were immediately taken to induce firms to make extensions to their works, and 19 firms, principally in the Birmingham, Sheffield, and Manchester areas, responded to the appeal.

This expedient, however, proved insufficient as soon as the demands of the national factories began to pour in. The department therefore went outside the small tool trade and assisted firms who were willing to undertake the manufacture of special tools and fixtures.

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[1] Appendix XII. [2] Appendix X.

Though no general control of the small tool trade was instituted till a comparatively late date, control of certain supplies which presented particular difficulty began in 1916, and it was in connection with these that Government enterprise was undertaken. Spade-cutters, chucks and taps all required special measures to obtain the increased output necessary, and, contrary to the procedure adopted in the matter of machine tools, the Ministry obtained control of special factories for this purpose.

National Tool Factory, Gateshead.—The most important of these was the National Tool Factory at Gateshead-on-Tyne for the manufacture of spade-cutters. In May, 1916, a disused building was rented for £120 a year from the Lumsden Machine Tool Company, and equipped with plant at an initial capital outlay of £7,000. New buildings were added towards the end of 1917, and the capital cost rose to £18,327 by October, 1918, but, compared with a monthly turnover of £12,000 in 1918, this was not an unreasonable amount. The whole of the money required for the establishment and the carrying on of the factory was supplied by the Ministry.

Production began in August, 1916, and by the end of the year the estimated output of 3,000 cutters a week was obtained. After the extensions, the remaking of cutters and the reclaiming from scrap of high speed steel which was reworked into smaller cutters was undertaken, and the output was raised to 5,000 a week, a supply adequate to meet all requirements.

The management of the factory was in the hands of Mr. Lumsden, of the Lumsden Machine Tool Company. He was appointed by the Ministry, and carried on the factory on most economical and up-to-date methods. It had been the intention of the department to carry on the factory on purely commercial lines, selling the product at the average market price. Under Mr. Lumsden's management it was found that the market price could be halved and still leave a considerable margin of profit. This result was obtained by standardisation of the cutter, by the use of special machines of Mr. Lumsden's own design, by the utilisation of scrap metal, and by the large use made of unskilled labour. In October, 1918, 95 per cent. of the labour at work in the factory was unskilled, and 70 per cent. of this was women's labour. The decrease in the cost of the cutter produced in the factory had the effect of lowering the prices of private firms who continued to produce spade-cutters, and was, moreover, reflected in the lessened cost of producing shell. In 1916 the spade-cutter cost approximately a shilling a shell bored, taking 6-in. shell as a basis. At the end of 1918 it was under a penny a shell bored, in spite of the increased cost of labour and material. This reduction was due not only to the decreased cost of the cutter, but also to the fact that the life of each cutter was very considerably lengthened by improvements in design and in the hardening process.

The Coats Machine Tool Company.—The output of the Coats Machine Tool Company consisted of tools of all kinds, including jigs, dies, boring bars, rifling heads and special reamers. It was taken

over by the Ministry, as the management was not considered satisfactory, and the output was poor both in quality and quantity. Originally a branch of a German firm, it had been transformed at the outbreak of war into an independent business under its former manager (Mr. Kotz), from whom it was taken over by the Ministry under the Defence of the Realm Regulations. It was placed under a manager appointed by the department, and financed by the Government as regards current expenses. This resulted in considerably improved output; and at the conclusion of the war the Ministry was able to show a satisfactory profit during the period of its control.

Messrs. Pratt & Co.'s Assisted Contract.—The supply of chucks early became a difficulty, and control of supply and distribution was instituted in May, 1916. This measure proving inadequate, it was supplemented by an arrangement with Messrs. Pratt & Co., of Halifax, to build a factory for producing chucks, towards the capital cost of which the Ministry advanced £20,000. The factory was begun in the latter part of 1916, and by May, 1917, it was delivering regular weekly supplies.

Birmingham Tap and Die Store.—A different method was adopted in dealing with the supply of taps. Control was instituted as early as 1916, but no special arrangements were then made to extend the sources of supply, though running contracts were given to existing makers. Later, owing to the enormous demands of the Air Board, a number of firms were persuaded to undertake the manufacture of taps and dies who had not previously made this class of tool. For instance, a firm making collar studs and buttons changed over completely to taps and dies, and gave large regular weekly deliveries with a percentage of rejections considerably below the average. A special store was opened at Birmingham to undertake the work of inspection and to sell the tools after they had passed inspection. These arrangements proved adequate to keep up a continuous supply of taps, and no further difficulty was experienced.

Grinding wheels and ball bearings were also controlled in 1916, in June and October respectively. As the supply of ball bearings presented special difficulties, it was shortly afterwards removed from the province of the Small Tool Section, and its history will therefore be dealt with separately. The home supply of grinding wheels was improved by the extension of manufacturers' works, but no direct Government enterprise was set on foot. A great deal of reliance was placed on importation in this respect, the supply of grinding wheels having been almost entirely in American hands before the war.

General control of small tools did not begin until September, 1917, when a start was made with imported tools by instituting a licence under the Board of Trade. In December a measure of control of merchants was added and in February, 1918, a demand for the control of small tools arose within the trade itself. This resulted in the Small Tools Order of May, 1918, applying the permit system to small tool firms from 1 June, 1918.[1] Owing to the short time the system was in

[1] Appendix XI.

operation its effect cannot be as clearly seen as in the case of machine tools.

The policy with regard to importation of small tools followed the lines of that of machine tools. The proportion of imported small tools to those of home manufacture was, however, greater than in the case of machine tools owing to the superior position that America had established in this respect before the war. The efforts made to increase the home manufacture tended to correct this, and the figures of the home output show how much was achieved in this respect. In December, 1915, the value of the monthly output from all makers was £78,295; in November, 1916, it was £174,895, an increase of over 123 per cent. Figures for the years 1917 and 1918 do not appear to be available. Though part of this increase was undoubtedly due to the increase in the cost of labour and material, the greater part of it can be rightly attributed to the actual increase in output.

(*e*) Control of Cranes and Lifting Machinery.

In March, 1916, a section of the Machine Tool Department was instituted under the control of Mr. T. Evan Davies, whose work proved invaluable, to deal with cranes and other kinds of lifting and conveying machinery. The problem here was the same as that facing the department with regard to other kinds of machinery—the adjustment of an insufficient supply to meet an ever-increasing demand—and the means adopted to deal with it were, broadly speaking, the same. All orders for lifting machinery had to be submitted to the department and permits and priority classification were given to those allowed to proceed. Thus the first step in all control was taken—the elimination of work not strictly necessary for the conduct of the war. Monthly progress reports and notification of the completion of orders had also to be sent in by every firm controlled by the department.

As these measures did not entirely solve the problem, the control of second-hand machinery was taken over towards the end of 1916. Information was required from all in possession of lifting machinery which was not being used, and from this a register was compiled which proved of great value in dealing with the distribution of cranes for war purposes. Permits were necessary for the sale of second-hand machinery similar to those issued for new machinery.

No government factories were established for the purpose of enlarging the supply of lifting machinery, as the close control of distribution succeeded in co-ordinating supply and demand fairly successfully. Neither was any control of prices found to be necessary. The Crane Section, like the other sections of the Machine Tool Department, avoided, wherever possible, the direct placing of contracts, but a certain number were placed in connection with machinery for the Russian Government in 1916.

The number of firms coming under the control of the Crane Section was about 210, and the value of the work controlled was, in 1917, £7,000,000 to £8,000,000 a year.

(f) Work in Relation to Stampings and Castings.

The direction by the Machine Tool Department of the supply of drop forgings and malleable iron and small steel castings forms an admirable example of the *ad hoc* character of much of the department's work. Though forgings and castings are closely allied to raw materials, the Machine Tool Department took up the question because one of the obstacles to the supply of machine tools was found to be the lack of adequate supplies of forgings and castings, which are the rough shapes of metal from which all machinery is manufactured. The work of the Stampings and Castings Section, for which Mr. R. M. Atkinson was responsible, was to organise and increase the production of the stamping and casting trades, as well as to co-ordinate supply and demand. The preliminary step of obtaining information as to supplies and demands disclosed a grave shortage of drop forgings for almost all war purposes, and a serious deficiency of small steel castings for aeroplane and motor transport work. Malleable iron castings were in a considerably better position, but in all the trades a lack of organisation was found which resulted in inferiority in quality as well as paucity of output. Accordingly, the section instituted the usual measures to control output, arranging the relative urgency of work and the proportion of civil to munition work which could be allowed. In order to improve the quality of the output, an interchange of visits between the different firms was encouraged, specialisation of manufacturers in certain directions was instituted, and improvements in processes, as, for example, the adoption of heat treatment plants and the substitution of friction lifters for hand-lifted stamps, were established. With the approval and assistance of the department many firms extended their works and their plant, though no direct Government activity was set on foot except in the case of malleable iron castings. With regard to these it was proposed that research should be undertaken in order to improve the methods employed in castings and to conserve the supplies of hæmatite iron, of which there was a considerable shortage. A small foundry at Brentford was taken over under the Defence of the Realm Act for this purpose with its manager and staff, and an analytical metallurgist was appointed by the Ministry.

As the work of the Stampings and Castings Section developed, it became obvious that it was growing beyond the scope of the Machine Tool Department. Forgings and castings are necessary not only for machinery, but for almost all munitions, and therefore they needed to be dealt with by a department with a greater opportunity for co-ordinating and regulating requirements. With this object in view, the control of stampings and castings was transferred to the Steel Group at the end of 1917, and this section of the department ceased to exist.

(g) Equipment of National Factories.

One of the most important aspects of the department's work was the assistance it rendered in equipping government factories. The establishment of so many new factories for munitions of all descriptions

entailed a heavy demand for new machinery, which could only be met by careful organisation. At first the department was not consulted at all about contracts for machinery for the National Shell Factories, orders being placed wherever machinery could be obtained and at practically whatever prices contractors chose to demand. But the chaos and extravagance resulting from this procedure soon led to an alteration. From the autumn of 1915 all orders for machinery for National Shell and Projectile Factories were placed only after consultation with the Machine Tool Department, which was thus enabled to allocate capacity to the best advantage and to keep a check on prices. The general policy of the department was to act as technical adviser to the National Factory and as a *via media* between the management and the contracting firm, taking no direct responsibility for the placing of contracts, except as regards the approval of prices. But this procedure had to be modified later on, the department itself placing orders for most of the national factories. In order to decentralise and hasten the work, resident inspectors were appointed to most of the National Projectile Factories in May, 1916.

The equipment of the national factories established during the latter part of the year presented a somewhat easier problem, because there was by this time in existence a large stock of government-owned machinery, which could always be traced through the agency of the Central Clearing House. A certain amount of the equipment of new factories could thus be effected by transference of machines from factories where they were no longer required owing to a change in the type of work being dealt with, and thus the sudden heavy demand which the entire equipment of a new factory entailed was to some extent lessened and a considerable saving was effected.

(*h*) Extended Gun Programmes.

In March, 1917, a very urgent demand came to the department for machine tools for the repair and relining of field guns. This demand necessitated the turning over of several large shell plants to gun repair and later on to gun manufacture. Machine tools for shells were naturally unsuitable for guns, but in view of the urgency of the change it was decided to adapt large numbers of shell machines for gun work. The alterations were extensive, and were mainly carried out by the factories with the advice and assistance of the Machine Tool Department. For the large number of new machines required, specifications were prepared and orders placed by the department. Many of the large machines were split up into units, which were manufactured by a number of firms and assembled into the complete machine by the parent firm. The work of organising this supply was considerable, and the difficulties of inspection great, as many of the firms were new to the work, but it was all successfully accomplished in good time. To carry out the work the department originated several new machines; for example, radial shapers for breech rings, which performed mechanically work previously done by hand, and combing machines for gun tubes.

(i) SUPPLIES TO ALLIES.

A problem which faced the Machine Tool Department throughout its whole existence was that of meeting the demands of our Allies. Their plight was even worse than our own, since their industry was not developed to the extent of ours, and they had been in time of peace large importers of German machines. Yet with an output insufficient to meet our own requirements, it was impossible for us to do more than supply a proportion of their needs. Even that was not always possible. In August, 1915, instructions were given by the Minister that all supplies of machine tools to the Allies were to be stopped till the war demands in this country were satisfied. This drastic order was moderated as the situation at home became less difficult, and supplies were resumed. But no general policy was laid down, at all events in the earlier days of the Ministry, and in practice the department was left to gauge the position for itself, and to reconcile conflicting demands, acting on the general idea that British requirements must have primary consideration, but that the demands of the Allies must also be met to the greatest extent possible.

In order to keep a strict control over the export of tools, it was decided in March, 1916, that no machine tools for the Allies were to be authorised by the department unless previously approved by the Commission Internationale de Ravitaillement. Machinery for Russia was, however, an exception to this procedure, all orders for Russian requirements being placed by the Russian Government Commission in co-operation with the Machine Tool Department. The requirements of Russia in the earlier part of the war accounted for the greater number of machine tools exported. Owing to political developments, exports to Russia declined during 1917, and the demands of France and Italy became the chief preoccupation. In March, 1918, the situation in England was such that export for the Allies had once more to be seriously curtailed, and this close restriction continued until the date of the Armistice, when the regulations governing export were modified as a preliminary to their total withdrawal in December, 1918.

In spite, however, of restrictions, the supply of general machinery for the Allies amounted to no inconsiderable sum in value. In 1917 the applications of the Commission Internationale de Ravitaillement dealt with by the Machine Tool Department amounted to about £10,000,000; and the value of tools undelivered at the date of the Armistice was £453,697, France and Italy between them accounting for nearly three-fourths of this amount.

(j) OUTPUT.

Figures of sanctions and deliveries do not seem to be available before June, 1916, and then are incomplete, as far as they have been found. The indications are, however, that the value of machine tools sanctioned between June, 1916, and November, 1918, remained fairly steady. For the last seven months of 1916, the average monthly

value was £1,118,170. During 1917 it appears as £1,060,398[1]; in 1918 it rose again slightly to £1,101,712 for the ten months, January to October. This is what would be expected, since in 1916 the demand for new equipment was particularly heavy, and in 1918 the falling off in American supplies necessitated increased output at home. The upward trend of the figures from July, 1918, indicates a much increased programme of British manufacture. As regards the total amount of machinery required, the figures are misleading, since they take no account of transference of machinery, which increased steadily during 1917 and 1918. It appears, therefore, that the total demand for machinery rose steadily throughout the war, and was appreciably higher in 1918 than in 1916.

The figures of sanctions give some indication as to the relative balance of demand from various industries at different periods. The largest demand came steadily from the munition industries co-ordinated under the Ministry, but demands from other sources fluctuated considerably. In 1916 sanctions for the Allies came next in value, being about 30 per cent. of the whole; in 1917 they fell to a comparatively small amount, but rose again towards the latter part of 1918. The figures for aeroplane construction are interesting as showing the rising urgency of this supply. In 1916 the sanctions for War Office and Admiralty aeroplane requirements combined were smaller than those for the Allies; in October, 1917, they had risen to a total almost equalling that of the sanctions for Ministry of Munitions contracts. At the beginning of 1918 aeroplane sanctions were included in those for the Ministry and the Admiralty respectively, and the result was a marked increase in the sanctions for both departments. The value of the Admiralty sanctions in October, 1917, was £35,922; in January, 1918, it was £109,678. Similarly, Ministry sanctions rose from £63,532 to £100,561. Though this cannot be attributed entirely to the demand for aeroplane construction, the greater part of the increase undoubtedly comes from that source, which continued to appropriate a large part of supply during 1918. Admiralty demands were always fairly high, showing a tendency to increase largely in 1917, when machinery was urgently required for the construction of mine-sinkers and other naval devices. The sanctions for the War Office remained small throughout.

Figures of deliveries are available only for 1918. The average monthly value of the deliveries for January to October was £863,586.[2] The actual delivery figures for each month fluctuate considerably, and there is no indication of increased delivery to correspond with the increased programme. But this could hardly be expected, since delivery on sanctions given in the latter months of 1918 would not appear to any appreciable extent till 1919. It is practically impossible to compare sanctions and deliveries except over large periods of time. Broadly speaking, the deliveries for 1918 correspond

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[1] This is for nine months only, the figures for July to September being missing.

[2] Appendix XII.

more nearly with the sanctions of 1917 than of 1918, and in so far as any conclusion can be drawn from such rough data, the balance of supply and demand appears to have been very fairly attained in 1918, considering the increasing scarcity of labour and the general difficulties attending the supply of all munitions.[1]

IV. Price Control.

The control of prices formed one of the most onerous duties of the Machine Tool Department. It was an extremely difficult one, because not only was each firm making tools of its own design, which differed from similar classes of machines made by its competitors, but also in pre-war days makers had devoted themselves to the production of machine tools of different grades and qualities; and the prices established on these lines represented the quality of their manufactures as appraised by buyers in the open markets of the world. Regulation of prices was therefore a very delicate matter, and in this respect the advice and co-operation of the Machine Tool Advisory Committee proved of the utmost value. Representing as they did some of the largest machine tool firms in the country, the members, by submitting their own business to control, gave the rest of the trade a guarantee of good faith, while their knowledge of the conditions of manufacture enabled the department to impose general price regulations which would not discourage manufacture, and which would allow as much consideration as possible for individual interests. Control was most rigidly applied to machine tools and wood-working machinery. Small tools were on a much more flexible basis, while cranes and stampings and castings were not controlled by any direct order, though the prices charged by manufacturers were from time to time investigated. The limitations enforced on the machine tool trade applied not only to tools sold for use in this country, but also to those exported to allied countries and to the colonies, as far as existing agreements between manufacturers and their foreign agents permitted.

(a) MACHINE TOOLS AND WOOD-WORKING MACHINERY.

Price regulations differed according to the class of trader, whether he were manufacturer, merchant or importer. The question of makers' prices first occupied the attention of the Machine Tool Department. Between August, 1914, and July, 1915, prices, left to themselves, had risen very considerably, and it was felt that an

[1] See History of the Machine Tool Department, Part II. by Sir A. Herbert (HIST. REC./H/1700/1); Notes by Mr. P. V. Vernon on work of T.M.2 (HIST. REC./H/1700/2); Notes by Mr. Atkinson on work of T.M.5 (HIST. REC./H/1700/3); Notes by Mr. Steven on work of T.M.3 (HIST. REC./H/1700/5); Replies of Machine Tool Department to Questionnaire of Reconstruction Committee, April, 1917 (HIST. REC./R/1700/11); Papers relating to Machine Tools (HIST. REC./R/1700/32); National Small Tool Factory, Gateshead, (D.D.G.(T)/2528); Minutes of the Machine Tool Committee; *Review of Munitions Programme*, September, 1917; Output Tables, 1918, D.M.R.S.

attempt must be made to keep them within reasonable limits. At this date the department had no definite power to enforce price regulations, and therefore any limitations in this direction could only be carried out with the consent of the trade.

On 29 July a circular was issued, asking makers to undertake voluntarily not to make any increases in their prices above those quoted on 1 July, 1915, without the consent of the Minister. The members of the Machine Tool Committee, on the part of their firms, took the lead in agreeing to this proposition, and their example was followed by the majority of the firms in the trade. This does not mean, however, that prices did not increase; it only means that increases were made, for the most part, with the knowledge and consent of the Machine Tool Department. Applications for increased prices were dealt with in detail by the permanent staff of the department under the guidance of those members of the committee who were not members of the trade, as it was undesirable that information as to their competitors' profits should be gained by certain manufacturers through their official position. When an application was sent in details were required as to the costs of labour and materials as compared with pre-war cost. This was then set against the price ruling on 1 July as compared with pre-war prices, and on the evidence of this applications were either granted or refused.

This system depended entirely on the willingness of the manufacturer to submit his prices to the control of the department; if he did not choose to do so, he was perfectly free to make any profit he could from the extraordinary pressure of demand. In order to check this practice on the part of a few firms, the earliest opportunity was taken to place price control on a compulsory basis. The application to machine tools of Regulation 30A of the Defence of the Realm Act in August, 1916, permitted their sale on conditions,[1] and one of the conditions embodied in the permit was limitation of prices according to the rules laid down by the Ministry. Firms who had not been limiting their prices were required to credit their customers with any over-charges they had made since 1 July, 1915, before they were granted permits.

At this period the applications for increases in price became very numerous, owing to the cumulative effect of the steady rise in the cost of material and labour. The investigation into the particulars of individual firms thus became a great tax on the department and the committee, as well as entailing a great deal of extra work on the part of the already overworked manufacturer; and it was felt that it would be an advantage if a simpler system could be adopted. Being now controlled establishments, the machine tool firms came within the scope of the Munitions Levy, and this effectually prevented them from benefiting by charging high prices. Therefore the *raison d'être* for close investigation no longer existed. Moreover, for the purpose of the Munitions Levy, the Controlled Establishments Section now had in its possession information which was substantially the

[1] Appendix IX.

same as that being supplied by the firms directly to the Machine Tool Department. The old system of detailed information and investigation was therefore abolished. Manufacturers were asked simply to give a written assurance that increases, if sanctioned, would not result in a higher percentage of profit on turnover than was obtainable during their standard period, and this assurance was checked by the information of the Controlled Establishments Section. If this profit had been below 10 per cent. prices were sanctioned which would allow a profit of 10 per cent. This was the general system adopted after August, 1916, modified, however, by other factors. Quality of workmanship was taken into consideration, and the position of manufacturers who had to quote for delivery a long time ahead. In such cases firms were allowed to increase their prices by 5 per cent. more than the increases that would have been allowed were the revised prices to take effect immediately.

In January, 1917, the Munitions Levy was abandoned, and controlled owners became subject only to the Excess Profits Duty. The control of prices by the Ministry therefore assumed considerable importance, since a manufacturer was now allowed to retain a percentage of his excess profits whether they were derived from increased output or increased prices. An incentive was thus given to increase prices, and it became necessary to examine price applications with greater care again. To meet this difficulty, the Prices Sub-Committee was instituted in June, 1917.[1] One of its first actions was to advise an alteration in the basis of profit allowed. Owing to the great inflation of selling values which took place in 1917, the pre-war percentage of profit on turnover was thought to be no longer justifiable. The sub-committee recommended that in future the Ministry should reduce the firm's turnover in selling values for the last financial year by 50 per cent. of the amount by which it had been inflated by increases over pre-war selling prices, and fix prices which would allow the firm to make its pre-war percentage of profit on this reduced turnover. This recommendation was adopted and acted upon by the department.

The periodical increases in wages, which became more and more frequent from the summer of 1917, resulted in a rush of applications on these grounds whenever a wage award was announced. It was, therefore, suggested that an automatic increase in prices should be allowed to firms on the approved list to meet this particular difficulty, and in October, 1917, the principle was adopted. It was not applied, however, for every wage increase, since some of these would not have uniform effects throughout the trade. Automatic increases followed the awards taking effect on 1 December, 1917, 1 August, 1918, and 17 December, 1918. On the other hand, it was not considered that the 12½ per cent. increase to skilled men given in November, 1917, and the 7½ per cent. on piece-work of January, 1918, justified automatic increases, and each application was dealt with on its merits.

With the encouragement of sub-contracting to obtain increased output, the question of the exploitation of the sub-contractor came

[1] See above p. 42.

before the department. Machine tool manufacturers were first asked voluntarily to limit their profit on sub-contracted machines to a certain percentage of the actual price paid to the sub-contractor. When the contractor supplied drawings and patterns and supervised the work this percentage was to be 10 per cent.; if working drawings only were supplied, it was to be limited to 5 per cent. In cases, however, when only a few machines were sub-contracted, a margin of 15 per cent. gross profit on cost was allowed if all services were performed by the contractors and the number of machines was three or less, 12½ per cent. if the number was six or less. This arrangement took effect from 17 August, 1915, and continued on a voluntary basis till 28 August, 1916, when it was embodied in conditions of the permit under Regulation 30A. Thus it became obligatory on contractors, and those who had not conformed previously had to give rebates from 17 August, 1915.

The close control of merchants' prices was even more important than that of manufacturers, for merchants were not subject to the Munitions Levy, but only to Excess Profits Duty. That it was necessary may be judged from the following instance. The maker of a certain 6½-in. lathe charged £35 16s. to the merchant who bought it. He sold it at £62 to a second merchant, who passed it on at £66 to a third. This merchant again sold it to another merchant for £70, and he sold it to the user at £87 15s. Thus between maker and user there intervened four middlemen, and the price was increased during the process by £51 19s.

Like manufacturers, merchants first agreed to limit their prices voluntarily. A conference between representatives of the merchants and the Machine Tool Committee was held on 18 August, 1915; and it was agreed that merchants should not increase the existing rate of gross profit, and that in no case should the price to the user exceed 10 per cent. upon the maker's price, no matter how many merchants intervened between maker and user. These conditions were to apply to all orders taken by merchants after 17 August, 1915, but were not to include small tools or individual articles of a value of £10 or less. Neither did they apply to the sale of second-hand machines.

When Regulation 30A was applied to machine tools, this agreement was incorporated as one of the conditions of a permit to sell. The limitations therefore became compulsory, and merchants who had refused to abide by the agreement were required to rectify their transactions as from 17 August, 1915.

The prices of second-hand machines were limited from 28 June, 1916, when a regulation was issued that they should not exceed 80 per cent. of the current market price for new tools of the same type. Thus, though no maximum percentage of profit was laid down, the sale price of such machines was effectively controlled at a time when the supply fell considerably short of the demand. In September, 1918, it was proposed to revise the regulations, and definitely restrict the merchants' profit on second-hand machines to 20 per cent. This was approved by the Merchants and Importers' Advisory Panel, but owing to the improved military situation, and subsequently to the Armistice, the regulation was not put into force.

In November, 1917, an application was made to the department by representative merchants that a higher percentage of profit on new tools should be sanctioned, because working expenses had increased and the volume of business had decreased, owing largely to the Ministry's policy of arranging supply directly with the manufacturer whenever possible. Detailed information as to the position of these merchants' business did not appear to warrant an increase, and as they were not supported by the production of information by the general body of merchants the matter was dropped. In March, 1918, the question was again brought forward, but the Machine Tool Department felt that the information at their disposal did not justify any action being taken at that time, and with this view the Advisory Committee concurred. When the question was once more raised in October, the signing of the Armistice made action unnecessary.

As regards imported machines, the immediate effect of the outbreak of war was a great inflation of prices. The sudden increase in demand made it easy for importers to fix prices which allowed a considerably higher percentage of profit than was customary before the war. Moreover, the business attracted a large number of speculators who had not previously undertaken the importation of machine tools, and who were prepared to offer high prices to the American manufacturers. Thus there was the temptation for the manufacturer to sell to the highest bidder, and prices were artificially forced up.

This state of affairs was ended by the Proclamation of 30 November, 1915, prohibiting the importation of machine tools without licence from the Board of Trade. Licences were only issued to those firms who had been engaged in importing to a considerable extent before the war, or who acted as sole agents to manufacturers abroad, and price regulations were incorporated in the licence as one of the conditions of its issue. In the issuing of licences the Board of Trade acted solely upon the advice of the Machine Tool Department, with whom the responsibility rested.

In order to ascertain what might be considered a fair proportion of gross profit for importers the books of five representative firms were examined and on their evidence 18½ per cent. on the c.i.f. costs at the British port was the amount of profit fixed. This was the average percentage of gross profit before the war. This rate of profit was reduced in February, 1917, to 12½ per cent. on the f.o.b. cost of a machine tool where the cost was £40 or more, and 18½ per cent. on the f.o.b. cost where it was under £40 and over £10. In March and October, 1918, as a result of the decreasing importation from America, applications were made for the profit to be raised to 18½ per cent. irrespective of value, but on the evidence available it was not considered that such an increase would be justified. In December, as a result of the Armistice, all restrictions on the sale of imported machine tools were withdrawn, though a certain measure of price control over small tools was still exercised by the Board of Trade.

These regulations applied to second-hand as well as to new tools. Later the regulation referred to above limiting the maximum prices of second-hand tools to 80 per cent. of the price charged for a new machine, was applied to imported machines. This double regulation had the effect of discouraging the purchase of second-hand machine tools at high prices in America.

Special terms were given by certain importers for machines for National Projectile Factories. They agreed to supply the machine tools of American makers for whom they were sole agents in this country at a profit of 2½ per cent. only on the net cost of the machines as delivered at the factory, a percentage which would probably not even cover the cost to the firms of arranging for the supply. The approximate value of the orders placed on this 2½ per cent. basis was £143,500.

(*b*) Small Tools.

The question of controlling prices in the small tool industry did not arise till January, 1917, and then, in view of the fact that all the larger firms were controlled establishments, it was not felt necessary to lay down definite regulations to govern prices. Manufacturers were told that they must keep their prices within reasonable limits and the percentage of profit on turnover should not be higher than in their two pre-war years.

The first definite step towards control was taken in September, 1917, when the Ministry decided to control the importation of small tools under licence of the Board of Trade, in the same way as machine tools were already controlled. The profit on imported small tools was to be 25 per cent. on the cost at the importer's warehouse. It was found on examination that this would entail hardship on small retail dealers, and in such cases an increased profit was allowed, provided the price to the user did not exceed 35 per cent. of the cost at the warehouse. This arrangement came into operation in November, 1917.

Control of importers' prices inevitably led to control of merchants' and manufacturers' also. Regulations governing the commission made by small tool merchants were drawn up in December, 1917, on the basis of the practice ruling in the trade before the war.

In February, 1918, the control of makers' prices was definitely taken in hand, and the Small Tools Order issued in May embodied the regulations. They were considerably less detailed than those operating with regard to machine tools. Control was to be exercised in the simplest possible form, and wherever possible the submission of prices by individual firms was to be avoided. Maximum prices were to be, in the case of tools of standard type, those obtaining in the permit holder's business at the time his permit was issued, and in the case of special tools, such as were approved by the Ministry from time to time. All prices were subject to revision at any time by the Ministry, and if found to be too high, refunds might be required.[1]

[1] Appendix XI.

The Small Tools Order came into operation on 1 June, 1918, but as a result of the Armistice control became unnecessary, and it was withdrawn in February, 1919.[1]

V. Relations with the Trade—Supply of Labour.

As the organisation for control was developed, the relations between the department and the trade necessarily became closer, and the effective working of the regulations depended on the harmony with which these relations could be maintained. Though from the departmental point of view close control meant efficiency, economy and increased production, from the point of view of the manufacturer it might easily appear irritating interference and increased burdens. If in controlling the trade the department experienced considerable difficulties, so did the manufacturers in satisfying the demands of the department for information as well as for speedy execution of orders, in obtaining labour and material, and in dealing with sub-contracting on the scale necessitated by the increased demand. It was impossible that the period of control should pass without friction of any kind; it says much for the goodwill shown by both sides that such friction as there was never hindered output, and that cordial relations between the Ministry and trade representatives were maintained to the end.

(a) ATTITUDE OF THE TRADE TOWARDS CONTROL.

Undoubtedly one of the reasons for the smooth working of control was the presence of the Machine Tool Advisory Committee, but that body did not always represent adequately the feelings of the whole trade, and from time to time complaints reached the department, through the medium of the Machine Tool and Engineering Association. Two deputations in particular were sent, one in June, 1917, and another in June, 1918, and the opinions expressed by these may be taken as showing the principal grievances of the manufacturers. The root of their opposition was undoubtedly to be found in the control of prices, which, they contended, put a premium on inefficiency. In their view, where a firm made large profits it was due to better business methods, and could not therefore be deemed profiteering. In seeking to reduce war profits the Ministry was eliminating the incentive to efficiency, and adopting a fundamentally wrong policy. Even admitting, for the sake of argument, the necessity of price control, the makers urged that the system instituted by the department was very inquisitorial, that returns for a period of seven years were quite unnecessary, and involved an undue amount of work considering the depleted state of clerical staffs, as well as the disclosure of firms' private business concerns to their competitors.

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[1] See History of the Machine Tool Department, Part II. by Sir A. Herbert (HIST. REC./H/1700/1); Memorandum of Price Control, by Sir A. Herbert and Mr. Edward M. Iliffe (HIST. REC./H/1700/4); Notes on T.M.2 by Mr. P. V. Vernon (HIST. REC./H/1700/2); Minutes of Machine Tool and Small Tool Advisory Committees and Merchants and Importers' Advisory Panel.

The policy of the department in insisting on merchants' discount on Government orders was another great grievance of the trade, as the makers considered that this practice penalised firms who dealt through merchants as against those that dealt directly. The control of small tools also evoked considerable discontent, as it was felt that the hardships of control would press particularly heavily on a trade in which the price of articles was often so small that the profit allowed would not cover the increased cost of production under control, and in which the difficulty of fixing standard prices was particularly great owing to variations in design, and in quality of workmanship and material even in the same class of article.

In answer to these criticisms the department pointed out that the practice of obtaining merchants' discount was a general policy in the Ministry, and that the machine tool trade was not being treated any differently from other trades. The control of small tools was necessary because of the profiteering which had been steadily increasing throughout the trade and was particularly flagrant in certain cases. As regards the whole question of price control, the views of the trade and the department were diametrically opposed. The latter disputed the view that the method adopted put a premium on inefficiency, and said that since control was considered to be in the national interest, it would continue in force, though concessions might be made to mitigate hardships where they could be shown to exist in individual cases. The department justified the system of returns on the ground that information over a period of seven years was necessary to obtain a basis of comparison between war turnover and peace turnover on which the whole system of price control was based, and argued that in efficiently managed offices the information should be readily accessible and should not entail an undue amount of extra labour.

Dissatisfaction expressed by the trade really centred in the question of administrative control; of dissatisfaction with Ministry direction in regard to methods of manufacture there appears to have been comparatively little. This side of the department's activity constituted one of the most valuable parts of its work. The lack of organisation and the general conservatism which prevailed in the trade at the outbreak of war left room for much assistance in speeding up output, and in the introduction of new processes and new methods of production.

This work was very largely done through the inspectors of the Machine Tool Department, who visited firms and advised them how best to overcome their difficulties, and to produce more rapidly with less efficient labour. Standardisation of tools may be quoted as an example of the work done to increase industrial efficiency, and the importance of this may be gauged by the fact that while in January, 1916, only 14 taps were known to be standardised for munition work, in May, 1917, the number was 2,361. The specialisation of firms on particular types of machines was encouraged by the department, and insisted upon in 1918 when the withdrawal of American supplies made closer organisation a necessity. Limitation of design was another method adopted somewhat earlier to achieve the same end: in October, 1917, firms were forbidden to manufacture machines of new

design without sanction, and similarly sanctions were but sparingly given to merchants and importers to deal in machines which hitherto they had not touched. Manufacturing processes were supervised to the extent of laying down a rule that a single coat of chocolate coloured paint only was to be given to machines as a finish. In respect of trade secrets and the co-operation of firms with one another, the department had a hard battle to fight, for the jealous guarding of trade secrets may be said to be an axiom of industrial policy, and the extent to which it was successful shows that the machine tool firms, in spite of grumbling and evasion of regulations, were really anxious to co-operate with the Ministry in the matter of getting the utmost possible output.

(*b*) EVASION OF REGULATIONS.

That evasion of the regulations took place is only to be expected. Especially in the earlier period of control the temptations to evasion and the loopholes provided by an incomplete organisation were many. Tools were supplied without sanction, accounts were kept irregularly to conceal the fact, unauthorised advances in selling prices were made, sub-contracting, importing and merchant regulations were not observed. Second-hand machines were sold as scrap; in fact, every possible type of evasion that ingenuity could suggest appears to have occurred. In July, 1916, an inspector reported that, "in practically every case I have visited breaches of the regulations are taking place." Firms when brought to book pleaded that they "had been no worse than other firms." The institution of the permit system in August, 1916, enabled the department to check very considerably these irregularities, since a threat of withdrawing the permit to trade was generally sufficient to reduce recalcitrant firms to order. If they refused to refund excess charges (and evasion of price regulations were by far the most usual), the department carried out its threat. During 1917 and 1918 a number of firms had their permits cancelled, and though applications for renewal were frequent they were hardly ever sanctioned. In this respect the department consistently enforced a firm, almost severe, policy, for, as the Machine Tool Advisory Committee said in one particularly flagrant case, "if drastic action were not taken, their effort to enforce the regulation . . . would have been a failure." That a severe policy justified itself may be gathered from the fact that evasions of the regulations gradually became less and the percentage of cases, where they could be traced, was ultimately not large. Mr. John Varley was responsible for the supervision of the Investigation Section, and it was largely due to him that the regulations were in the end so consistently observed.

(*c*) SUPPLY OF LABOUR.

The labour problem in the machine tool trade was always a difficult matter, both to the department and to the trade. Machine tool manufacture requires highly skilled labour, and yet the rate of wages was lower during the war than in many other skilled trades where piece-work prices were taken into account. At the beginning of the

war the trade was one of the worst sufferers from the general migration to the army and direct munition making. Neither the men themselves nor the authorities seem to have realised at first the true significance of the machine tool industry, and consequently the depletion of the ranks of skilled machine tool workers became serious. As soon, however, as the mistake was realised, steps were taken to obtain the release of skilled men from the army and the reserves of skilled labour engaged upon work not of national importance, such as the jewellery and the joinery trades, were drawn upon.

In August, 1915, the Machine Tool Advisory Committee discussed the possibility of dilution with unskilled male labour and female labour, and manufacturers were circularised on the subject. From this time onwards a steady campaign to persuade firms to adopt female labour, and to educate them in the use of it, was carried on, but apparently manufacturers were not eager to co-operate in this respect. A certain number of firms tried the experiment: in September, 1915, it was reported that 22 firms had arranged female labour, and Messrs. Alfred Herbert, Ltd., said that it was proving most satisfactory. But judging by the number of circulars that were issued to the trade (October, 1915, November, 1915, February, 1916, when the slow progress of dilution was commented upon), this action was not general, and firms applied for skilled men to do work which unskilled labour could have performed with comparatively little training. The necessity of obtaining skilled labour for developing industries such as aircraft production, and the different "combs-out" as the war proceeded, gradually forced on manufacturers a more progressive policy. The proportion of women to men employed rose considerably. In January, 1916, only about 2·5 per cent. of the labour employed in the trade was women's labour; in June, 1917, it was 10·7 per cent.; in September, 1918, 24·4 per cent.[1]

During 1915 and early 1916 the policy of the Ministry appears to have been to make the machine tool trade a favoured industry in respect of skilled labour with the idea that when the pressure of demand for machine tools became less, these men could be drafted to other trades where the demand was more urgent. Unfortunately, owing to the constant extensions to old works and the building of new factories to increase the output of old types or to provide new types of munitions, the pressure of demand on the industry never became appreciably less[2], and thus a struggle set in between the Government and the manufacturers for the possession of this skilled labour. In July, 1916, the machine tool trade was asked to release 2½ per cent. of their skilled men for work in the National Projectile Factories and for aeroplane construction; in December there was a proposal to remove 3,000 skilled men out of a total computed at 14,000 in the machine tool and crane trades; and in October, 1917, 1,000 men were to be withdrawn for aeroplane work. The manufacturers met these proposals with energetic protests, and generally some modification was made to meet cases where particular hardship was inflicted. The figures of labour employed show, however, that the Ministry was to some extent

[1] Appendix XIII. [2] Appendix XII.

successful in its policy. In January, 1916, the total labour employed on machine tools was 42,269 workpeople; in January, 1917, it had fallen to 36,401; in January, 1918, to 29,000; while at the date of the Armistice it was about 27,000.[1] This result was achieved in spite of the continued pressure of demand by the more economical use of labour and by improvement in manufacturing methods.

The withdrawal of restrictions on the movement of labour and the removal of protection of skilled men reacted badly on the labour in the trade. The Machine Tool Advisory Committee protested against debadging and the withdrawal of leaving certificates. The latter especially proved a hardship, since migration from the industry set in at once. In 1918 this migration had assumed such serious proportions that manufacturers complained that it was threatening to destroy their whole organisation for post-war competition, since, though they would have suitable equipment, their skilled labour would have dwindled to a minimum. The attempt of some firms to cope with the difficulty by instituting bonus systems met with opposition from other firms, and no successful remedy had been found when the Armistice was signed and the whole labour question entered upon a new phase.[2]

VI. Liquidation of Contracts.

(a) LIQUIDATION.

Two days after the signing of the Armistice, the question of liquidation was discussed by the Machine Tool Advisory Committee. It had been arranged by the Minister that the Controller of the Machine Tool Department, Mr. Edward M. Iliffe, was to be responsible for the liquidation of all orders for machine tools, small tools and cranes. Mr. Iliffe was fortunate in securing the help of Mr. J. W. Milne, who was appointed Assistant Liquidator; and the Advisory Committee expressed its willingness to give "disinterested advice in helping the Ministry in the transition stage from war to peace."[3] Machine tools presented the greatest difficulty, since by far the larger amount of the contracts concerned came under this heading, and as the whole of the output had been closely regulated by the Ministry, the contractor could not be held responsible for delays in delivery or subjected to arbitrary cancellation without compensation on this account. In the case of small tools and cranes, output had been regulated in a few instances only, and therefore the general principles laid down by the Ministry with regard to cancellation and compensation could be applied.

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[1] Appendix XIII.

[2] See Deputation of Members of Machine Tool and Engineering Association (D.D.G.(T)/921); Notes on T.M.2 by Mr. P. V. Vernon (HIST. REC./H/1700/2); Minutes of Machine Tool Advisory Committee; *Review of Munitions Programme.*

[3] Minutes of Machine Tool Committee Meeting 256.

As far as liquidation was concerned, machine tools were divided into two classes : (*a*) Machines ordered for a special purpose, for which there would be no market after the cessation of hostilities ; (*b*) general purpose machines, which could be used for post-war work.

It was considered by the department that contracts falling into the first class should be dealt with individually, the contract being cancelled immediately and the amount of compensation being assessed by Government inspectors according to the work done under the contract, and on the lines laid down in the break clauses attached to all machine tool contracts. Contracts falling into the second class should be treated generally. If delivery to the Government were not required, contractors should be asked to relieve the Government of all its orders on the basis of a compensation of from 10 per cent. to 15 per cent., irrespective of the amount of work done upon the machine. The payment of this compensation would really be an economy to the Ministry, since if the machines were delivered they would be put to a certain amount of expense in finding a customer and selling the machine, as well as risking a possible depreciation in price in certain classes of machinery. In addition the proposal would relieve the Ministry of an enormous amount of work and responsibility.

These proposals were approved by Sir Gilbert Garnsey and the Minister, and the amount of compensation to be paid on standard machines was fixed at 12½ per cent. The members of the Machine Tool Advisory Committee undertook, as far as their firms were concerned, to accept a general settlement on these lines, and the work of liquidation was begun. By far the greater number of contracts were settled by payment of the 12½ per cent. compensation. Where there was any uncertainty as to whether machines were standard or not, the Machine Tool Committee adjudicated : for example, a contract had been placed with J. Butler & Co. for slab milling machines, which they decided could not be regarded as standard, and the Ministry therefore agreed to accept delivery and dispose of the machines themselves. In another contract with Kendall and Gent, where the machines were judged to be special, compensation at the rate of 22½ per cent. was paid. In some cases it was found that machines, though they could hardly be regarded as special, had certain departures from standard type which would render sale difficult, and in such cases the committee recommended that a higher percentage than the normal 12½ per cent. should be paid : for example, on a contract with Messrs. Craven Bros. for double-headed shaping machines. The value of the completed orders for machine tools, small tools and general machinery at the date of the Armistice slightly exceeded £3,100,000. Of this total the various Government Departments for whom the orders were placed stated that they required deliveries to the value of over £1,000,000, which left contracts to the value of approximately £2,100,000 to be liquidated in the most economical manner possible. Of this total deliveries were accepted to the value of slightly over £200,000, and the goods passed to the Disposal Board for sale. Of the remainder compensation was paid to the extent of a sum slightly in excess of £220,000, or 11% of the value of the goods cancelled,

which left a saving of approximately £1,680,000, or 89% of the commitment value. These figures were subsequently modified, as instructions were received for further orders to be cancelled, but the percentage cost of the liquidation of contracts not required remained substantially unaltered.

The liquidation of contracts for imported machine tools was, with the approval of the Merchants and Importers' Advisory Panel, carried out on the general lines adopted in the case of British made machines. It was decided to withdraw all restrictions on the selling prices of imported machine tools from 9 December, 1918.

(b) Disposal of Government Property.

The disposal of Government-owned machine tools in the various national factories and loaned to private firms was undertaken by the Surplus Stores Disposal Board, and did not come within the scope of the Machine Tool Department.

(c) Demobilisation of Committees.

By the end of April, 1919, it was decided that there was no longer any reason for retaining the services of the Machine Tool Advisory Committee, of which Provost W. B. Lang had acted for nearly two years as a most efficient Chairman. It was therefore dissolved, having held 270 meetings since its inception on 20 July, 1915. The Merchants and Importers' Advisory Panel and the Small Tool Committee had already been dissolved in February. The Machine Tool Department continued in being to finish up the work of liquidation, but with the demobilisation of the committees its close and continuous connection with the trade was severed. Of the value of the committees' work there can be no two opinions. Though as advisory bodies they were only able to make recommendations, their representative character and intimate knowledge of trade conditions gave their recommendations very considerable force and their close co-operation with the Controller and executive officials of the Machine Tool and other departments of the Ministry prevented their recommendations from degenerating merely into pious aspirations. It is true also that the regulations for the control of the industries were almost invariably proposed by the Controller of the department to meet constantly changing circumstances. Thus the Committees did not to any extent initiate policy. But in so far as these regulations were submitted to the committees with the reasons which prompted their suggestion, and then discussed by them, and often modified and improved, they exercised a considerable influence on their application. The machine tool trade was the earliest and ultimately the most closely controlled of all industries, and the success of the experiment was largely due to the fact that control was carried out with the consent of the trade itself, expressed through its representatives on the Advisory Committees.[1]

[1] See Minutes of the Machine Tool Advisory Committee.

CHAPTER III.

BALL BEARINGS.[1]

I. Introduction.

Experience of warfare on the scale on which it was waged during the years 1914 to 1918 revealed unsuspected weaknesses in the industrial organisation of all the belligerent countries. In Great Britain one of these weaknesses was the failure to realise early enough the importance as a limiting factor in production of a comparatively small component in manufacture, or of certain kinds of industrial equipment. Instances of the latter are machine tools and gauges, the inadequate supply of which was one of the prime factors in delaying and limiting the output of munitions in the early months of the war. A crucial instance of the former may be found in the history of ball bearing supply.

Bearings are a component of all apparatus for mechanical transport; whether it be bicycle, motor, tractor, or aeroplane, they are an essential part of the motor machinery. For commercial purposes a steady demand for bearings must always exist, and even before the war there was a tendency for this demand to become larger as motor transport played an increasing part in industrial organisation. The possibilities of mechanical transport revealed early in the war resulted in a sudden increase in demand, and when the part to be played by aeroplanes and tanks was realised by the military authorities, a situation developed which amounted practically to a revolution in the whole conception of the scale and relative proportion of munitions supplies. The reaction of this on the ball-bearing situation was to produce a demand which the existing organisation was totally unable to meet, of which even the manufacturers had but little prevision, and for which correspondingly little attempt had been made to create fresh sources of supply. The failure to deal with the situation seems all the more remarkable in view of the fact that the pre-war demand had been met largely by importation, a great proportion of which (two and a quarter million bearings annually) was from Germany. To this extent, therefore, supply was automatically reduced in August, 1914. Thus there would have been difficulty in meeting a normal demand in such circumstances: to meet an extraordinary one was obviously impossible. Yet beyond individual efforts on the part of one or two ball-bearing firms to extend their works, nothing effective was done until the middle of 1916, when the

[1] See Record of Ball Bearing Supplies, prepared by the Ball Bearings Branch, and Appendix containing copies of agreements, reports, correspondence and statistics (Hist. Rec./H/1700/7).

situation was absolutely critical. A conference called to discuss the matter in July revealed the fact that even on the manufacturers' own estimates, which were likely to be liberal, only about 55 per cent. of the existing demands could be met from home supplies, and the decreased importation could not possibly supply the remaining 45 per cent. Belated efforts were made to remedy the evil; central organisation was set up and large extensions to factories were at once put in hand.

Unfortunately, demand did not wait for these efforts to bear fruit and produce equilibrium. The rapidity with which aerial and mechanical warfare came into play as decisive weapons in the field caused it to go up by leaps and bounds, and in July, 1917, there was little improvement in the situation. At this date the total output, both from home and foreign sources, was only 85 per cent. of the estimated requirements to the end of 1917, while the new programmes of the Aeronautical Department and of the Mechanical Warfare Department would raise the demand in 1918 far beyond anything the existing sources could supply even when the extensions authorised in 1916 came into full operation.

Drastic action was imperative to save the situation. An Advisory Committee was appointed to review the whole position, central organisation was improved, and instructions for further large extensions were issued to the chief supplying firms at home. Pressure was put on foreign sources to increase their supplies and American help was obtained to the fullest possible extent. The result of this concentrated activity was that slowly matters began to improve. The discrepancy between supply and demand diminished, and something approaching equilibrium was apparently obtained in 1918. But the facts revealed in 1916 and 1917 show that it was only the energetic action of the Ministry that prevented disastrous consequences resulting from the previous lack of foresight, and even their best efforts could not prevent delay in the output of tanks and aeroplanes at a time when the greatest possible supply of these was a factor of vital importance in military operations.

II. Organisation and Functions of the Ball Bearings Branch.

(a) ORGANISATION OF THE BRANCH.

For industrial purposes ball bearings are included with other appliances in the term small tools, and thus their history properly belongs to that of the Small Tools Section of the Machine Tool Department. An attempt was made at first to deal with them in this section. But the nature and organisation of the ball bearing industry at the outbreak of war was such that the problem of supply differed in many respects from that of small tools in general, and it was ultimately felt that an independent organisation was necessary to deal satisfactorily with the difficulties created by war conditions. Thus a separate branch was established which remained part of the organisation of the Ministry of Munitions till the termination of the war.

Administrative action was first taken in the summer of 1916. In March the Minister had been approached by the French Government to assist them in obtaining increased supplies of balls from the Hoffmann Company, who were, in the words of M. Albert Thomas, "presque l'unique fournisseur des Alliés,"[1] and doubtless this request led to a review of the state of the whole industry, which revealed the urgent necessity for immediate action. In July a conference was held at the Ministry for the purpose of discussing the situation with the representatives of the departments chiefly interested in the supply, and Mr. J. D. Steven, the Director of the Small Tool Section of the Machine Tool Department, was instructed to extend the activities of his section to cover the ball bearing industry.

In spite of the efforts of the Small Tool Section, further organisation became necessary in July, 1917. An Advisory Committee, consisting of Sir Alfred Herbert, Mr. Steven and Mr. Percy Martin, Director-General of Petrol Engine Supply, was then appointed, and as a result of their report the Minister decided that a Ball Bearing Branch should be established, affiliated to the Machine Tool Department and working in close connection with the Aeronautical Supplies Department. Mr. Steven was appointed Director of the branch in addition to his work as Director of the Small Tools Section.

A year later all connection with the Machine Tool Department ceased. The branch was at the service of so many departments, not even confined to the Ministry, that it was found that affiliation to any particular one resulted in confusion. So from July, 1918, it continued its work as a self-contained section, grouped for establishment purposes only with the Aircraft Production Department and responsible to Sir Arthur Duckham as Member of Council.

(*b*) Functions of the Branch.

The work done by the Ball Bearings Branch can be divided into three sections, the provision of bearings of the types and (as far as possible) the quantity required, their distribution among the services requiring them in accordance with the varying urgency of their demands, and the control of exports and imports. To understand the problem which the branch had to face, the position of supply when the matter was first taken in hand by the Ministry and the conflicting nature of the demand must be briefly indicated.

The material included under the general term "ball bearings" should be more specifically divided into ball bearings, roller bearings, steel balls and steel rollers. For the supply of these there existed in England six firms, but one only, the Hoffmann Manufacturing Company, manufactured all classes and sizes of the four components. The Auto Machinery Company manufactured steel balls as well as bearings, but the other four firms manufactured bearings only, either ball or roller or both, and were dependent for their supply of balls either on the Hoffmann Company or on foreign sources. Thus the

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[1] Hist. Rec./H/1700/7, Appendix B1 (a).

Hoffmann Company were the key to the whole position as far as the home supply was concerned, and on this firm's ability to maintain its output depended the output of the whole industry. In addition to these six firms, there were two foreign sources of supply, the Svenska Kullager Fabriken of Sweden, supplying ball bearings complete and some steel balls, and the Schmidt-Roost Company, Switzerland, supplying ball bearings complete only. The Swedish House was represented in England by the Skefko Company, of Luton, one of the six firms alluded to above, and the S.R.O. Company had an English agency in London. The great drawback to supplies from these two firms was that all the raw material for manufacture had to be exported from England, and thus to the dangers and uncertainty of transport was added the difficulty of keeping them adequately supplied with material. Up to the middle of 1916 there was no appreciable importation of balls or bearings from America, and generally the American product was not equal in quality to the British product. Taking both home and foreign sources of supply into consideration, the total ball and roller bearings available in October, 1916, were 208,652 per month.[1]

For this supply there existed the most varied demand, as ball bearings play an essential part in many industries. The chief Government Departments requiring supplies in 1916 were the War Office, the Admiralty, and the Ministry of Munitions (the Mechanical Transport Department, the Central Clearing House, and the Service Bicycles Section). Later developments in the matter of tanks increased the requirements of the Mechanical Warfare Department enormously, and as the aeroplane programme was extended, those of the Aircraft Production Department became equally urgent. Outside the Government Departments, supplies were demanded by the Commission Internationale, the Russian Government, the Dominions and India. Beyond these, again, there were the requirements of private manufacturers, especially cycle makers, but as this work fell into "Class C" it need hardly be considered in dealing with the relation between supply and demand. Inquiries addressed to the different departments concerned, to foreign Governments, and to Colonial representatives elicited requirements of 246,404 bearings of all classes monthly, and this was not by any means the total, since the requirements of the Dominions and India had not been received when the report on the matter was made. Putting this beside the figures of supply, there was a deficiency of nearly 38,000 monthly,[2] and if the importation figures were deducted, the deficiency in the home supply was shown to be at least 103,000, or 42 per cent. This is the figure which should really be kept in mind, since there was the possibility of importation being stopped entirely and, in any case, dependence on importation was not a policy to be commended.

[1] Based on estimates by supplying firms.

[2] This is the estimated deficiency; actually it was greater, because the firms' estimates of output were too sanguine. See below, p. 89.

With such a deficiency the necessity of increasing supplies was obvious. Three methods suggested themselves, control of the industry on the lines instituted by the Machine Tool Department, extensions to home factories, and a considerable increase in importation. All these expedients were adopted, but their value as sources of increased supply varied very much. Comparatively little could be done to increase output by control since the industry had been specialised before the war to an extent which left practically no field for increase by modernisation of method. Standardisation on any large scale was impossible, because the existing types and sizes were so numerous that the time involved in effecting alterations would more than counterbalance any ultimate good arising from standardisation. Measures had already been taken to meet the labour difficulty and to make the utmost use of the available labour by organising night shifts. The policy, therefore, which was being applied with considerable success by the Machine Tool Department generally could not hope to be successful in this particular matter, and it was necessary to look to other sources for a real solution of the problem. Increased importation, though a necessity, was, as has been said, not an ideal policy. The department was therefore forced to resort to the third method, large extensions of existing factories in England, and consequently its activity in this direction far outbalances that of the Machine Tool Department.

The importance of the work done by the branch in allocating output is made clear by the facts of supply and demand. The priority classification, which for bulk supplies was P.4, automatically gave manufacturers some guidance as to relative urgency of demand, and supplementary instructions were issued by the department from time to time. For example, special instructions were given to the Hoffmann Company in January, 1917, to give aircraft orders preference over mechanical transport orders, and at various dates instructions were issued for imperatively urgent work. But in the spring of 1917, as the aeronautical demand increased both in amount and in urgency, the position of manufacturers became very difficult. The instructions of the inspectors of the Aeronautical Department clashed with those of other departmental inspectors quoting a high priority for their orders. This led to a definite ruling being made that absolute control of the order of execution of supplies by the manufacturers was vested in the Ball Bearings Branch, and that all inspectors requiring a special priority for their orders must take up the matter with the branch and not with the firm executing the order. This action relieved the manufacturers very considerably, but led to the branch being flooded with departmental requests for preferential treatment for special contracts. As it was impossible to satisfy all individual applications, it became necessary to devise some system whereby the rival claims of different departments could be automatically adjusted.

The method adopted was that of departmental allocation on a percentage basis. The requirements of the respective departments were ascertained, and a proportionate percentage of the total available supplies was allotted to each department, which would then determine

for itself the relative precedence of orders placed on its behalf, so long as the allotted percentage was not exceeded. Each department thus benefited automatically by every increase in output, and the relative balance of demand was maintained. This scheme met with the approval of all departments except the Aeronautical Department, whose increasing programme was a source of great anxiety. At one period this department attempted to safeguard its supplies by placing orders on its own responsibility with three general engineering firms, the Blackstock Engineering Company, Messrs. Vickers, of Crayford, and the Components Munitions Company, Limited. These firms were instructed to manufacture ball and roller bearings in connection with the A.B.C. engine programme. The prejudicial effect of such independent action on allocation of supplies was obvious, and the Ball Bearings Branch at once took up the matter with the Aeronautical Department. The working of the scheme appears to have shown that the department's premonitions of a shortage for really urgent requirements were not fulfilled, and the increasing rarity of departmental requests for assistance during 1918 show that on the whole the scheme was a success in working. As supply more nearly met demand, the importance of allocation naturally became less, but it always remained as a means of dealing with what proved to be one of the greatest difficulties the branch had to face, the conflicting demands of the number of departments interested in the supply.

III. Control of the Ball Bearing Industry.

(*a*) CONTROL OF SALE AND MANUFACTURE.

The order under which the ball bearing industry was rigidly controlled was published on 1 November, 1917, as a result of the decision to create a Ball Bearings Branch at the Ministry, which should relieve the Small Tool Section and enable more attention to be paid to the matter of ball bearings. Under the terms of the order nobody could manufacture or deal in ball bearings, roller bearings, or any part of these without a licence issued by the Ministry. The qualifications for a licence were that the applicant must be

(1) A bona fide manufacturer of balls or ball bearings;

(2) A recognised agent for a foreign firm or an independent importer of three years' standing prior to 31 December, 1917;

(3) A dealer in balls and ball bearings as part of the ordinary course of his business as a merchant or garage proprietor with a business of three years' standing as in the case of the importer.

Under these conditions 131 licences were granted. Exemptions from the order were made for the purchase of ball or roller bearings within the United Kingdom, and for the sale of bearings as part of a complete machine or for automobile repairs.[1]

[1] See Appendix XIV.

Under the terms of the licence manufacturers had to submit weekly returns of their output and orders in hand, and importers and dealers monthly returns of stock, purchases and sales. These particulars enabled the department to grade output according to the urgency of demand and to keep in touch with stocks which would be available in cases of emergency.

(*b*) Control of Prices.

In January, 1918, price control was instituted owing to the increasing amount of exploitation which came to the notice of the branch.

Representatives of the trade were consulted, and it was laid down that on orders up to and including £10 in value a maximum percentage of 25 per cent. might be added to the net cost on delivery to the customers' warehouse by the manufacturers, while on orders above £10 the maximum percentage was to be 12½.

On the whole, control was accepted by manufacturers and dealers as an inevitable necessity. A certain number of traders, as might be expected, attempted to do business without a licence, but cases of this kind were often tracked by the help of the censoring authorities. Gradually the recalcitrant firms came into line, and control worked smoothly till the order was suspended on 7 January, 1919.

IV. Extensions to Factories.

The amount of financial assistance given by the Ministry to ball bearings firms for extensions varied considerably according to the importance of the output, both as to type and quantity, and to the general efficiency of the firms. Of the six firms previously mentioned, four made considerable extensions to their works with Government assistance. These were the Hoffmann Company, the Skefko Company, the Electric and Ordnance Accessories Company, and the Ransome and Marles Bearing Company. One, Messrs. Mair, Nixon & Ferguson, of Kettering, received slight assistance for plant additions (£1,000 was lent by the Ministry in September, 1917), while the Auto-Machinery Company, of Coventry, rendered no assistance at all. In marked contrast to that of other firms, their attitude was "the reverse of helpful."[1] They practically demanded that the Government should defray the whole of the cost of any extensions, and were so antagonistic that, except for insisting on the installation of certain machine tools essential for an important aeronautical contract, the branch made no definite attempt to influence the firm's policy, and the output of the company remained stationary at 9,000 bearings a month. The failure of the Auto-Machinery Company to co-operate was, however, to some extent counterbalanced by the enterprise of the Rudge Whitworth Company, who with Government assistance built an entirely new factory for the production of ball bearings.

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[1] Hist. Rec./H/1700/7.

The help rendered by the six firms varied markedly, and this variation must be put down to the business organisation of the different firms, since the difficulties which faced them were for the most part general. All suffered from shortage of building materials and labour for their extensions; all found great difficulty in obtaining the necessary plant to equip them; and all had to face the usual problems of shortage of raw material and productive labour. The Ball Bearings Branch gave all possible assistance in these matters, working in close co-operation with the Machine Tool Department, the Labour Supply Department, and the Iron and Steel Department. But the value of its help depended largely on the co-operation of the firms concerned, and a comparison of the results attained by the different firms under practically similar general conditions shows that ultimately the deciding factor in increased output was the efficiency and goodwill of the individual manufacturer.

(a) THE HOFFMANN MANUFACTURING COMPANY, LTD., CHELMSFORD.

The Hoffmann Company was already the leading firm in the ball bearing industry when the Ministry took up the problem of increasing output. In July, 1916, they were producing approximately 90,000 bearings a month and had extended their works out of their own resources to attain this output, their capacity early in 1915 being about 72,000 monthly.

On 20 July, 1916, a meeting of representatives of the Ministry and the Company was held to discuss the question of further extensions. It was arranged that these were to be put in hand at an estimated cost of £75,000. The Ministry was prepared, if necessary, to make advances from time to time up to a sum of £140,000 to cover the cost of these and the earlier extensions and to supply working capital. Such advances were to bear interest at 1 per cent. above the current Bank of England rate and were to be repaid within three years of the termination of the war. No definite increase in output was mentioned in the agreement nor was the date of completion of the extension stipulated, though time was to be "the essence of this agreement."[1] In October, the firm said they hoped to finish the extensions by March, 1917, and to increase their output by 50 per cent. on that obtained during the early months of 1915. This meant that at least 108,000 monthly might be expected, and 120,000 was the amount which they hoped to reach ultimately.

Serious delays were experienced with regard to the extensions, which led to a special liaison officer being appointed to follow up each difficulty as it arose. This improved the situation very considerably, and output on a small scale began in May, 1917. In July the extensions were giving a substantial output, and by January, 1918, the output of 120,000 monthly was being considerably exceeded.

[1] HIST. REC./H/1700/7, Appendix A.4.

A second extension was undertaken in June, 1917, as a result of the sudden increase in the aeronautical programme at that date. The capacity of the factory was to be increased to 175,000 monthly by June, 1918, and the firm considered that the cost of the necessary new buildings and plant would be from £500,000 to £750,000. Provisional sanction was given by Sir Arthur Duckham in order to avoid delay, and the firm prepared plans and placed contracts for the work. A formal agreement was not, however, made, because in August the question arose of taking over the Hoffmann works entirely, and the extension became involved in this. As a result of the taking over of the factory, the Department of Factory Construction took the extensions in hand and they were well under way by December, 1917. Difficulties with regard to supplies of steelwork then intervened, so that it was the summer of 1918 before the first sections were ready and equipped. After that date much more rapid progress was made, and at the date of the Armistice practically the whole of the extensions were in operation, and the output for October (five weeks) reached nearly 230,000 bearings.

Messrs. Hoffmann had been extremely unwilling to assent to the extension scheme of 1917, as it would treble the pre-war capacity of the works, and they feared that their post-war business would not be big enough to enable them to utilise such extensive buildings. Moreover, they would have difficulty in finding working capital and were unwilling to increase their indebtedness to the Ministry. When the Ministry insisted that the extensions must be carried out in the national interest, they suggested that the works should be taken over as a national factory, to be carried on by the present Managing Director of the Company, if the Ministry so desired. The Ministry was not very willing to adopt this course, and pressed the Company to extend their works with Government assistance. Negotiations on these lines were going on when the scheme for the erection of a new factory by Messrs. Rudge Whitworth was brought forward. If this was to succeed it was essential that the co-operation and technical assistance of Messrs. Hoffmann should be secured. But it was unlikely that the firm would assist in building up a new business which would compete seriously with their own organisation after the war without a very substantial *quid pro quo*. The Government therefore began to consider the idea of purchasing the Hoffmann business outright and thus taking the two Managing Directors into Government service in order to utilise their business capacities not only at the Hoffmann works, but also at the Rudge Whitworth factory.

Negotiations for purchase were begun in August, 1917, and in September provisional terms were agreed on by the Ministry and the Company. The assets of the Company were to be valued as at 30 September, 1917. From this valuation were to be deducted all liabilities and outgoings of the Company up to the same date (including the liability for the current Ministry loan), but not any liability incurred for the new extensions. The difference was to represent the purchase price to be paid by the Ministry for the assets. In addition a sum of £515,000 was to be paid for the goodwill of the business. This figure

was arrived at by averaging the profits of the Company between 1913 and 1916 and taking five years' purchase. This offer was to be conditional on the two Managing Directors entering into an agreement to place their services unreservedly at the disposal of the Ministry.

The Company estimated that under this arrangement the purchase price for the assets would be £1,000,000. Accordingly, therefore, in asking for Treasury sanction, the Ministry named £1,515,000 as the total sum to be paid to Messrs. Hoffmann. The Treasury firmly refused to sanction this sum, saying that the sums both for the assets and the goodwill were extravagant. The Ministry pointed out that if the independent valuation judged the assets to be less than £1,000,000 the lesser sum would be accepted under the agreement, and justified the goodwill price by the urgency of the situation, and the value of the firm's technical knowledge, but the Treasury still refused to entertain the proposition. Protracted negotiations followed with the Company, and it was only a threat of taking over the works under the Defence of the Realm Regulations that finally brought the firm to making concessions that the Treasury would recognise as a basis for agreement.

In efficiency the Hoffmann Company appears to have reached a high standard. Their failure to attain their increased output by the dates specified was largely due to causes beyond their control, and when these difficulties were removed they made up their leeway with surprising rapidity. In order to meet the shortage of skilled labour, they instituted a training school at the works where unskilled labour was trained for different operations before being put to work on machines engaged on actual production. Dilution was carried out by the firm to a remarkable extent, considering the highly skilled nature of the work and the high standard of work guaranteed and maintained by the firm. In July, 1918, the percentage of skilled labour at work was only 6·4, the remaining labour being women (43·5 per cent.), boys (6·5 per cent.), and semi-skilled men. In reporting on the firm the liaison officer in charge of the extensions stated that the firm was "to be congratulated on the spirit in which they tackled every difficulty which arose, and on the manner in which they maintained the highest possible output even whilst changing over and occupying extensions as they became available."[1]

(*b*) Skefko Ball Bearings Company, Ltd., Luton.

Besides acting as an agency for the Svenska Kullager Fabriken of Sweden, the Skefko Company was engaged on the outbreak of war in manufacturing bearings from materials supplied from Sweden, and the maximum capacity of their Luton factory when the question of extensions was brought up was about 20,000 bearings a month.

In the spring of 1916 the firm approached the Controlled Establishments Section with regard to putting in hand extensions to their bearing plant which would double the output and cost about £80,000. The Company was prepared to find this sum if the Ministry would agree, in dealing with the accounts of the Company as a controlled

[1] Hist. Rec./H/1700/7.

establishment, to write down the expenditure to the post control value to the Company of the assets provided by the expenditure. To this proposal the Controlled Establishments Section assented, but owing to delays on the part of the Treasury, who were not satisfied as to the urgency of the matter, the formal agreement was still uncompleted in July, 1916, when the ball bearings conference took place. The conference considered that the extension was so important that authorisation should be given to the firm to proceed at once, with an assurance that an equitable arrangement would be arrived at with the Finance Department. Negotiations continued on the basis of the Controlled Establishments Section's letters, and eventually it was arranged that the cost of the extensions was not to exceed £100,000, and was to be written down to 60 per cent. of the cost of the buildings and 50 per cent. of the cost of machinery and plant.

Though time was stated to be "the essence of the agreement,"[1] the work of extension proceeded very slowly. A special officer was appointed early in 1917 to deal with difficulties, but the speeding up which followed a similar appointment in the case of the Hoffmann Company was noticeably lacking at the Skefko works. It was not till September, 1917, that the buildings were completed, and later still before they were equipped and in running order.

The position of the bearing plant was complicated by the erection of a new ball factory which was authorised in 1916. The advisability of the Company's manufacturing their own balls instead of depending entirely upon the parent firm in Sweden was urged at the Conference of July, 1916, but the manager of the Skefko works was decidedly opposed to this suggestion. Pressure was brought to bear on the firm by the Ministry, who felt strongly the necessity of cutting down imports and avoiding risks of loss in transport. The effect of this was that the Company agreed to erect a special ball factory to produce from fifteen to twenty million balls a year, at a cost not exceeding £125,000. Towards this sum the Ministry agreed to make advances from time to time, such advances to bear interest at 1 per cent. above the current Bank of England rate, and the whole loan to be repaid not later than three years from the termination of the war. The Company stated that they hoped to finish the factory and begin production by May, 1917.

This factory, however, shared the fate of the bearing extensions. The buildings were not completed till the end of 1917, and further delay was caused by the non-delivery of the ball-producing plant from Sweden. Even when the factory was equipped, labour could not be obtained to work it. As there was nobody at Luton skilled in ball production, experts had to be sent from Sweden to superintend the erection of the machines and to train labour for production. Difficulties with passports delayed the arrival of these men till the spring of 1918, and production did not begin till July, 1918. Even then the firm failed to attain anything like the promised output. The maximum

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[1] Hist. Rec./H/1700/7, Appendix A.5.

reached was under 6,000 balls a month, whereas the estimated output when the factory had been sanctioned more than two years previously was between nine and eleven thousand a month.

In spite of the unsatisfactory progress of the 1916 extensions, the need for increased supplies became so urgent in 1917 that it was decided that the firm must be instructed to put in hand new extensions. In August the Company submitted plans which would allow of an increase of 100 per cent. in their output of bearings and 50 per cent. in their ball output. In September, these plans were sanctioned by the Ministry, and an agreement was made for the carrying out of the scheme. The estimated expenditure was £50,000 on buildings and £175,000 on plant. Depreciation was to be allowed to the extent of 40 per cent. of the expenditure on buildings and 50 per cent. on plant. Advances bearing interest at 6 per cent. and not exceeding in all £500,000 were to be made by the Ministry to provide for capital expenditure and working capital, and the loan was to be repaid within five years from the termination of the war.

As in previous agreements, no date for the completion of the work was laid down in the contract, but the Skefko Company mentioned three or four months from the time of beginning work as a possible date. The building licence was issued by the Munitions Works Board in November, but in March, 1918, the buildings were far from finished. In a confidential report made to Sir Arthur Duckham at this date it was stated that the Company considered that the architect was responsible for the erection of the buildings, and did not therefore make much attempt to help in the difficulties arising in connection with material and labour. There was an unnecessary amount of importation of plant from Sweden and too much dependence on Swedish experts, no attempt being made "by the officials at the Luton Works to set the plant to work or to teach their employees how to operate the machines."[1] Moreover, the Company was very averse from dilution of labour and it was only after great pressure that they agreed to employ women. In view of these facts it was hardly surprising that the promised increase in output failed to materialise. A personal visit from Sir Arthur Duckham and changes in the management of the factory which took place about the end of April produced more enthusiastic co-operation, with the result that sections of the new shops were at work by the end of the summer, and at the end of October all the buildings were finished. The substantial increase in output which this promised was not however needed, since the Armistice was signed just as production was getting under way.

(c) THE RANSOME AND MARLES BEARING COMPANY, LTD., NEWARK.

The works of the Ransome and Marles Bearing Company originally belonged to Messrs. A. Ransome and Company, wood-working machinery manufacturers of Newark. In 1916 a new company was constituted which took over the factory for the production of bearings of large size

[1] HIST. REC./H/1700/7, Appendix C.12.

and of special rather than standard type. The average output in 1916 was 5,500 bearings a month, which, considering the class of bearing manufactured, was equivalent to 10,000 a month of the Hoffmann or Skefko type.

Early in 1917 the Company began to extend their works in order to undertake a large War Office contract for aeroplane engine bearings. The estimated cost of the scheme was £37,000, and towards this the War Office contributed £21,637 13s. 4d., under the name of the "War Department Loan." Loan and interest were to be repaid by the deduction of 25 per cent. of the invoice price of the bearings supplied under the agreement. When in the summer of 1917 the question of a general increase in output was under consideration by the Ministry, the latter approached the firm to extend their scheme for the War Office and merge it into a Ministry agreement. Further extensions were to be made to the works at an estimated cost of £87,000, and the Ministry was to allow "as a grant to the Company"[1] 40 per cent. of the total expenditure on buildings and 50 per cent. of the total expenditure on plant and machinery. In addition the Ministry agreed to take over the amount owing to the War Office under the earlier agreement (£21,000) and to advance working capital as required. The grant for the extensions was to be deducted from the total indebtedness of the Company when the buildings were completed, and the balance was to be considered as a loan bearing interest at 1 per cent. above the current Bank of England rate, and to be repaid in full within three years from the termination of the war.

As a result of the original extension, it was estimated that the output would have risen to 15,000 a month by January, 1918, and an ultimate capacity of 30,000 monthly was expected when the further extension was completed. No definite date was laid down for the attainment of this figure, the "earliest possible moment"[2] only being stated.

In 1918 it was found that the original estimates for both extensions had been largely exceeded, and a supplementary agreement was entered into allowing for an additional £50,000 on the 1917 extensions. In addition provision was made for the erection of a small ball plant at a cost of £15,000, but owing to the signing of the Armistice no actual progress was made with this enterprise. In August, 1918, the total indebtedness of the Company to the Ministry was £209,000, of which £52,000 had been advanced for working capital and the remainder for the cost of the extensions.

Considerable delay occurred in the erection of the extensions owing to the shortage of labour. Lack of housing accommodation and low district rates of pay accentuated the difficulty. Progress grew more rapid in 1918, however, and at the end of the year the output was practically double that at the end of 1917.

[1] Hist. Rec./H/1700/7, Appendix A.13.

[2] Hist. Rec./H/1700/7, Appendix A.13.

(d) THE ELECTRIC ORDNANCE ACCESSORIES COMPANY, LTD., BIRMINGHAM.

No assistance from the Ministry was required by the Electric Ordnance Company till early in 1918. The works, which were the property of Messrs. Vickers, Ltd., gave a steady output of Timken Taper roller bearings at the rate of 4,000 to 5,000 a month during 1916 and 1917. In February, 1918, arrears in deliveries to the Mechanical Transport Department were so heavy that the Ball Bearings Branch undertook investigations, and got over the immediate difficulty by hastening deliveries of the machine tools required from America. These investigations showed, however, that no further output could be expected from the existing plant, and therefore when the Mechanical Warfare Department notified a large increase in their requirements in September, 1918, the question of extensions became urgent. The firm submitted their schemes at the end of September and approval was given by the Munitions Works Board on 14 October. Preliminary steps had already been taken by this time, and the extensions were therefore well under way when the Armistice intervened in November. According to the scheme, the estimated expenditure was to be £26,000, about equally divided between buildings and plant. The buildings were to be completed by 31 January, 1919, and the plant and machinery installed by 28 February. It was estimated that the output from these extensions would meet the demand of the Mechanical Warfare Department, but late in October the department put forward an amended programme with a 50 per cent. increase on their original demand. This could only have been met, had it materialised, either by further extensions or by importation of Timken bearings from America.

(e) RUDGE WHITWORTH, LTD., BIRMINGHAM.

The firm of Rudge Whitworth had not manufactured ball bearings before the war, but the need of supplies was so urgent that when the Company suggested taking up the industry in 1917, the Ministry gave the proposal most careful consideration. After considerable discussion with the Finance Department and the Munitions Works Board, the Company was authorised in August, 1917, to put in hand a combined bearings and ball factory to produce 80,000 bearings a month, together with their necessary equipment of steel balls. The work was begun on the basis of a draft agreement, which was converted into a formal one in January, 1918. Under the terms of this agreement the Ministry took over from the Company, under the Defence of the Realm Act, the land on which the factory was to be built, and empowered the Company to act as their agents in the erection and equipment of the factory. The whole of the capital cost was to be borne by the Ministry, to whom the building with its plant and machinery would, when completed, belong. The Company was then to lease the factory from the Ministry for the period of the war and one year afterwards at a rent which would be calculated to cover interest at 6 per cent. on the Ministry's total outlay, together with a sum to cover depreciation at the rate of 5 per cent. on two-thirds of the cost of the buildings

and 20 per cent. on one-half of the cost of the plant and machinery. At any time during their tenancy the Company had the option to purchase the factory at an agreed value, in which case the Ministry was to re-convey to the Company the land taken over under the Defence of the Realm Act. If the Company did not wish to exercise its option to purchase, the Ministry was to buy the land from the Company at its original cost, and the Company was to hand over the factory in good running order on the expiration of the lease. The whole output of the factory was to be sold to the Ministry at prices based on those of the Hoffmann Company, plus 15 per cent.

One of the chief reasons for taking over the Hoffmann Company in the autumn of 1917 had been to obtain the firm's assistance for the Rudge Whitworth venture, and therefore, in erecting and equipping the factory and deciding on the type of output, the Ministry worked on the assumption that the Tyseley factory would work hand in hand with the Hoffmann Company. The former works were to turn out standard types, while the latter concentrated on special and difficult types. The early manufacture of the Rudge Whitworth Company was thus carried on under the supervision of an expert from the Hoffmann Company. In May, 1918, bearings practically up to the Hoffmann standard were being turned out in small quantities. Where defects occurred, they were generally traceable to departure from the Hoffmann practice, and therefore the Company was instructed to adhere rigidly to Hoffmann methods rather than to try experiments and introduce "improvements" of their own.

Output was delayed by building difficulties rather than by failure to obtain the necessary plant, and it was not till June, 1918, that deliveries to contractors for the Mechanical Transport Department began. In August a large contract was placed with the firm by the Aeronautical Department, and deliveries under this order were rapidly being made at the time of the Armistice. Besides deliveries on contracts, the firm also sent a number of bearings into store. To October, 1918, the total output was 28,000 bearings, an achievement which was considered very satisfactory in view of the difficulties with which the firm had to contend and its relative inexperience in ball bearing manufacture.[1]

V. Importation of Ball Bearings.

(a) Disadvantages of Importation.

Reliance upon importation to meet a considerable portion of the demand was a matter of necessity, not of choice. Besides depending largely on the pre-war sources of supply in Sweden and Switzerland, the branch was obliged to develop a new source in America to meet the demands of the Mechanical Transport Department and the Aeronautical Department in 1917 and 1918. The disadvantages of this reliance on importation were, however, obvious. In the first place it involved considerable additional organisation. The export of the

[1] See Appendix XV. for statistics of progressive increase in home output.

raw material required to carry out orders placed with the Swedish and Swiss firms necessitated careful oversight to ensure that under cover of these requirements materials were not being taken out of the country for other purposes. Both the Foreign Office and the Admiralty required technical details as to the nature and use of every commodity to be exported before granting release, and thus the work of the branch was materially increased. Secondly, the transport difficulties were considerable, and delay and grave losses had always to be reckoned with. In October, 1916, the Skefko Company stated that during the preceding twelve months four consignments of ball bearings and components had been either sunk or captured by the enemy, involving a loss of 50,000 bearings and 500,000 steel balls. The branch therefore asked for special Admiralty protection for the cargo vessels, but this was not accorded until the loss of three more cargoes of supplies for the Aeronautical Department caused the latter to take action in April, 1917. Naval protection was then instituted, and losses in transit ceased.

A further difficulty, however, supervened in the blockade question. In the summer of 1917 the question of putting pressure on Sweden to stop her exports to Germany was raised by the Foreign Office. One of the possible results of such pressure would be to stop exports from Sweden to this country, and such a stoppage would vitally affect the ball-bearing position. The home supply at that date was totally inadequate to meet the demand, and the extensions to factories were all very much behind promises. In the last quarter of 1917 the Swedish supplies were equivalent to about 55 per cent. of the home supply. If the Swedish supply failed this amount must be provided either from home or other foreign sources. The probabilities of either of these being able to meet such an additional demand were exceedingly remote, and therefore the political situation was viewed with grave concern by the Ministry.

With regard to American supplies the disadvantage was chiefly a question of quality. There were a number of firms ready to undertake supply when the question was raised in October, 1916, but a strong prejudice existed among contractors in England against using American bearings on the ground of their unreliability. This prejudice was to some extent overcome as the result of experience, but the difficulty which then supervened was limitation in quantity, since the entry of America into the war automatically limited her ability to export munitions.

(b) EXTENT OF IMPORTATION.

In spite of all these difficulties importation increased rather than decreased. The importation figures from Sweden and Switzerland are considerably larger in 1917 than in 1916, while at the same time we were receiving considerable supplies from America, a negligible source in 1916. The effect of the extension policy at home was scarcely visible in 1918, since the total percentage of imports from foreign

sources continued to increase.[1] But had the war continued, the extensions would have come into full operation in 1919 and a very considerable decrease in importation compared with home production would probably have ensued.

The supplies from the Svenska Kullager Fabriken (exclusive of the output of the Skefko Company) always ranked next in importance to those of the Hoffmann Company. In 1917 the aeronautical demand was so urgent that the possibility of purchasing the whole output of the factory was entertained, and arrangements were made to pay a premium on all deliveries in excess of 100,000 a month, working up if possible to 200,000 a month. As the estimate of aeronautical requirements was afterwards modified, the proposal to purchase the whole output was abandoned. The highest average of Swedish deliveries worked out at 104,000 bearings a month between November, 1917, and October, 1918. This does not, however, indicate the total amount of importation from the Company, since besides complete bearings they supplied practically all the steel balls and various other components for the Skefko factory. The monthly average of steel balls imported during the period June, 1917, to October, 1918, was 1,042,719.

The estimated monthly supply of bearings from the Schmidt Roost Company was 25,000, but in practice they fell very short of this number, their average monthly deliveries over the period October, 1916, to September, 1918, being only 16,000. This was in spite of the fact that heavy supplies of raw material and Hoffmann steel balls were being despatched to the firm, so in the summer of 1917 a member of the Ball Bearing Branch went over to investigate the position. He reported that the Company were fostering their French trade "at the expense of the urgent requirements of our own Government,"[2] and that they also supplied a considerable quantity of bearings in Switzerland for general trade purposes. It was pointed out to the firm that under the arrangement for supplying raw material the English Government was to have the first call on their full capacity, and that they must divert a larger proportion of their output to England. That the pressure brought to bear on the firm was at any rate temporarily successful is shown by the fact that supplies from this company increased to 19,000 per month for the last quarter of 1917, whereas before they had not exceeded 12,000 a month.

Importations from America may be divided into three classes :—(i) importations for orders placed by the Ministry ; (ii) importations by the Hoffmann Company ; (iii) importations by ball bearing traders.

Orders by the Ministry were chiefly for bearings for the Mechanical Transport Department and for the Aeronautical Department. The first experimental contract was placed in January, 1917, and was quickly followed by others, with the result that in March about 240,000 bearings were on order. As these proved fairly satisfactory on delivery, a series of further orders was placed, 95 per cent. of which were for aeronautical service. Until March, 1918, a continuous supply of

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[1] See table on p. 89 below and Appendix XVI.
[2] Hist. Rec./H/1700/7, Appendix C.9.

high grade American bearings was received, and the importance of this source of supply was such that it was thought necessary to cable to the U.S.A. Government in June, 1917, urging them "to assist the Ministry of Munitions in the output of aeroplanes, motor transport and tanks by facilitating as far as possible the supply of ball bearings on order in the United States."[1] Owing to America's own needs, the supply gradually declined in 1918, but the average supply of bearings received from April, 1917, to October, 1918, was 50,000 a month.

The Hoffmann Company's imports consisted of magneto type bearings for high priority Government orders, chiefly aeronautical. The total imported was just over 100,000, and the course was adopted with the consent of the Ministry in order to allow Messrs. Hoffmann to concentrate on special bearings which were urgently needed.

Importation by traders consisted of lower grade bearings suited for general commercial purposes. These must have been imported during the whole period of the war, but no data of the amount of this importation were available till the Ball Bearings Order of November, 1917, made the submission of periodical returns of importation compulsory. From these returns it is reckoned that during the period November, 1917, to October, 1918, the monthly average of importation by traders was approximately 14,000. Adding this figure to that of Government importations, the total importation from America during this period may be placed at 64,000 a month at least.

VI. Results of the Work of the Branch.

In order to estimate to what extent the Ball Bearings Branch achieved the object for which it was created, the co-ordination of supply and demand, a series of comparisons should be made for each year of the war. Unfortunately, no data are available before October, 1916, the earliest figures being those furnished by the manufacturers in answer to inquiries which followed the ball bearing conference of July, 1916. Even these figures are not reliable, since the makers were unduly optimistic, and actual deliveries proved their July estimate to be decidedly too high. If the average of the actual deliveries for the last quarter of 1916 is taken, however, and compared with similar figures for 1917 and 1918 a broad indication of the increase in output can be obtained. The following table shows the relative output for these periods:—

Home Supplies.			Imported (America excepted).		Total Supplies (America excepted).	
Period.	Average Monthly deliveries.	Percentage increase.	Average Monthly deliveries.	Percentage increase.	Average Monthly deliveries.	Percentage increase.
Oct.-Dec., 1916.	127,675	—	59,333	—	187,008	—
Oct.-Dec., 1917.	174,216	36·5	108,804	83·4	283,020	51·3
Sept.-Nov., 1918.	229,270	80	128,254	116·1	357,524	91

[1] HIST. REC./H/1700/7, Appendix B.10.

American supplies are not included because they are not known with any degree of accuracy for the 1916 and 1917 quarters. The figures of total supplies for the year November, 1917, to October, 1918, have, however, been worked out, and the average monthly deliveries from all sources for this period was nearly 373,000. Thus, compared with the last three months of 1916, supplies had practically doubled.[1]

The increase in supplies is, however, of little value unless the relative demand is also known. Here again the data are disappointing. Only two really comprehensive statements of requirements were drawn up, one for the report on the ball bearing situation of October, 1916, and one compiled ten months later as a basis for the allocation scheme introduced in August, 1917. For the period October, 1916, to April, 1917, the estimated requirements were 246,000 monthly ; for August to December, 1917, 291,000. The following table shows the relation between supply and demand for these periods :—

Estimated Requirements.		Actual Supplies, exclusive of U.S.A.		Shortage.
Period.	Quantity.	Period.	Quantity.	Quantity.
Oct., 1916 to April, 1917	246,000	Oct. to Dec., 1916	187,000	59,000
		Jan. to Mar., 1917	201,000	45,000
1 Aug., 1917, to 31 Dec., 1917	291,000	July-Sept., 1917	250,000	41,000
		Oct.-Dec., 1917	283,000	8,000

The only figures of estimated requirements for 1918 are those of a memorandum placed before the Advisory Committee appointed in July, 1917. In this document the minimum requirements for 1918 are stated to be 423,000 a month, of which it was hoped that 367,000 could be obtained from home factories and the balance by importation. If this estimate of requirements remained valid it is obvious that the shortage, which was steadily decreasing in 1916 and 1917, rose again with a jump in 1918, since the average monthly deliveries from all sources during 1918 hardly reached 373,000.[2] It is probable, however, that at some time later than July, 1917, requirements were revised on a downward scale, and the deficiency was really less than the 50,000 a month indicated. No figures have so far been found to prove this, but it is supported by the fact that in 1918 the departmental clamour for supplies diminished very considerably, though the effect of the allocation scheme introduced in August, 1917, must also be taken into account. But from the figures available, it does not seem that supply had actually overtaken demand at the date of the Armistice, though the outlook for 1919 was promising.

[1] Appendix XVI. [2] *Ibid.*

In addition to meeting the problem resulting from war conditions, the activity of the Ball Bearings Branch has resulted in the creation of new assets for post-war industry. The extension of the existing factories and the erection of the new Rudge Whitworth factory will make it possible to meet the demand for ball bearings from home sources far more completely than before the war. The capacity of English factories was increased by over 80 per cent. between 1916 and 1918, and, with the shrinking of the demand to its normal dimensions, this increased capacity will be able to take up that part of it formerly met by importation. Thus, as in the case of gauges, new possibilities of employment and extended industry have been opened up for the future, possibilities which are all the more valuable because of the greatly increased use of ball bearings which the experience of war production foreshadows.

CHAPTER IV.

ELECTRIC POWER SUPPLY.[1]

I. Administrative Policy.

" Cheap and general power supply . . . . . goes to the root of all industrial prosperity . . . . . For all efficient factories motive power means electricity."[2] This is now regarded as an axiom of modern industry, applying not merely to emergency production, but to normal industrial organisation. So rapidly has opinion moved within the last five years that it is astonishing to find that only the most far sighted business men appreciated the full value of electric power at the outbreak of war. The majority of factories were still run on steam power, and though all manufacturers realised at once the necessity for a rapid extension of output in munition industries, only a minority appreciated the corresponding necessity for greatly increased supplies of electric power. This lack of insight had important results, both locally and centrally.

There are signs that locally, in certain areas at any rate, a restrictive rather than an expansive policy was adopted. The Yorkshire Electric Power Company closed down all extensions and capital expenditure from August, 1914, to the middle of 1915. The Town Clerk of Bradford, in an application for Government assistance for extensions in January, 1916, stated that, " from the commencement of the war up till the end of March, 1915, the number of applications for supplies of electricity was much below the average, as was the aggregate amount of energy demanded in connection with such applications." This reactionary attitude was not confined to the consumers ; the Corporation and the Local Government Board followed in their wake. Before the outbreak of war, the raising of a loan to cover the cost of installing a suction ash plant at Bradford had been sanctioned by the Local Government Board, but in March, 1915, one of the Board's Inspectors advocated deferring the installation. The Corporation fell in with this view, with the result that when the demand for increased power supply came, the Corporation was absolutely unable to meet it, and hand to mouth arrangements had to be made, with the resulting disadvantages of extravagance, insufficiency and delay.

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[1] See Hist. Rec./R/1380/1-11 ; Hist. Rec./H/1380-1 ; C.R.V/S/419, C.R./4382 ; Memorandum of Council Committee on Demobilisation and Reconstruction, Serial No. 122 ; Article in *Journal of Institution of Electrical Engineers* for May, 1919.

[2] Hist. Rec./R/1380/1.

The failure to appreciate the potentialities of electric power in production resulted also in a lack of provision for administrative control from the centre. When the Ministry of Munitions was established, no administrative machinery was set up to deal with this question. The Department of Gun Ammunition soon found, however, that one of the factors conditioning shell production was the supply of power, and that the laws of supply and demand being for the time in abeyance, some action must be taken to ensure that production and distribution should be adequate to meet the munitions demand.

(a) ELECTRICAL ENGINEER ATTACHED TO GUN AMMUNITION DEPARTMENT, JULY, 1915.

An experienced electrical engineer (Capt. McLellan) was appointed in July, 1915, to advise the department on all questions of power supply whether for the new national factories or for private contractors, in so far as the latter consulted the Ministry in their difficulties. This organisation was not, however, satisfactory. The question of power supply was too large a one to be properly treated as an adjunct of a department whose primary interest was shell production, while in the summer of 1915 the demand was already so urgent that there was no time to survey the field as a whole and plan a balanced comprehensive scheme of supply. The result was that the early efforts of the Ministry to meet the power problem were marked by a lack of concerted policy. Existing power stations were extended with little regard to their efficiency and post-war adaptability, and many new factories were equipped with private stations at considerable cost, whereas a more considered policy would have led to the supply being taken from existing sources. The result of these hastily improvised measures was chaos, inefficiency, and extravagance. The weakness of the position was fully recognised by Capt. McLellan, but the urgency of supply at this time was so great that ultimate desirability had to give way to immediate necessity.

As soon as possible, however, a definite principle of supply was enunciated. All consumers, whether Government enterprises or private organisations, should obtain their power from existing stations rather than generate it separately in private stations attached to their factories. Thus concentration in large units of production rather than dissemination in small ones would be promoted, with the immediate advantages of economy in labour, plant and materials, and the ultimate possibility of incorporating these units into any large scheme of electric power supply which might be promoted after the war. It was not desirable or possible to pursue this policy rigidly. In factories where waste heat could be utilised it was more economical to include a power station in the lay-out of the factory than to buy current from a public service undertaking. On the other hand, stations in the neighbourhood of new factories did not always exist, and a private power house had therefore to be built. But in large areas where there were existing facilities they were utilised : for instance at Sheffield, where there were several national factories, supplies of

power were obtained from the Sheffield Corporation, which carried out large extensions to meet the demand. As time went on and organisation in general improved, the exceptions to the general principle became fewer. The possibility of purchasing power from a local supply station was considered as one of the factors in choice of site for new enterprises, and Government sanction to erect private power stations was more and more sparingly given. Thus a progressive application of the principle took place, and when the Department of Electric Power Supply was instituted in June, 1916, it may be said to have inherited the principle as the charter of its foundation.

(*b*) Formation of Electric Power Supply Department, June, 1916.

The increasing amount of work involved in the carrying out of this administrative policy was the cause of the reorganisation which resulted in the establishment of the separate Department of Electric Power Supply. Capt. McLellan was appointed Director, and remained in charge of the department till August, 1917, when he was transferred to the Admiralty, and Mr. A. B. Gridley was appointed Director in his stead. Under his control, the department steadily put into practice the principle evolved under Capt. McLellan, directing the work of extending stations to meet the demand, helping the supply authorities to obtain financial assistance where necessary, and co-ordinating the requirements of the supply departments within the Ministry. Thus the existing demands of the supply departments, together with the possible sources of supply, all came within the purview of one central authority, whose knowledge of the whole industry enabled it to prevent overlapping and conflicting orders being given, to indicate a source of supply which would be both economical and efficient, and to organise an ordered and balanced system of supply in place of the *ad hoc* arrangements which earlier necessity had forced upon the Ministry.

(*c*) Appointment of Electrical Services Sub-Committee, September, 1918.

Though the Ministry solved its own problem to a large extent in 1916, it was hampered in applying its principles by the conflicting requirements of other Government Departments. The Ministry was by far the largest user of electricity, but the War Office, the Admiralty, and the Air Ministry all required supplies, while the conditions of supply for civil purposes were laid down by the Board of Trade and the Local Government Board. It was therefore found necessary to extend the principle of central administrative control established in the Ministry in order to bring about co-operation between the different Government Departments. As early as November, 1917, the Director of Electric Power Supply pointed out how the independent action of the other Departments tended to neutralise the efforts of the Ministry to obtain efficiency and economy. As an example he quoted the case of a repair factory at Battersea, which was being established in connection

with the A.S.C. under the ægis of the War Office. It was proposed to equip the factory with private generating plant, but investigation by the Electric Power Supply Department had shown that it was possible and far more economical to buy the current required from the Battersea power station. In spite of these representations, nothing was done to effect co-ordination at this time, but by the middle of 1918 conflicting Departmental requirements for most basic supplies had become so numerous that the War Cabinet War Priorities Committee was set up to consider the question from an impartial standpoint. This Committee appointed the Electrical Services Sub-Committee, consisting of representatives of all the Departments concerned under the Chairmanship of the Director of the Electric Power Supply Department. The work of this Sub-Committee was practically to review the whole field of supply and demand in order to secure uniformity of policy with regard to contracts and extensions, uniformity of practice in the use of electrical energy, and equilibrium between demand and supply both in the matter of power and electrical apparatus. This work included the approval of all applications for generating plant, either from Government Departments or any other source, and the recommendation of priority grading for power supply contracts between Government Departments and power supply undertakings. In this way it was hoped to eliminate the competition between Government Departments by allocating supply in accordance with the urgency of demand, and to save power companies and electrical firms the difficulty of deciding between competing Government orders. To a great extent the Committee succeeded in achieving its objects, and its work proved that it would have been of considerably more value had it been formed earlier in the history of the Ministry.

II. Extension and Control of Supply.

(*a*) EXTENSION OF SOURCES OF SUPPLY.

As the administrative principle of concentration of supply became more widely applied, the demand on the existing sources became correspondingly heavier, and the necessity for extensions became obvious. Existing stations were of four kinds :—

(1) Light and power stations carried on by Local Government Authorities, either Corporations or District Councils.

(2) Light and power stations carried on as a business undertaking by a company.

(3) Railway and tramway power stations.

(4) Private stations.

As sources of supply the two last were negligible, being either unsuitable for extension or fully occupied with supplying the demands of their own services. The Ministry therefore concentrated on encouraging the extension of municipal stations and company stations. The difficulties in the way were considerable. All electric supply authorities, whether municipal or private, are limited by the Electric

Lighting Acts of 1882, 1888 and 1909, laws which, in the words of the Board of Trade Committee on Electric Power Supply, are "unsuited to the present times." Besides this handicap, most of the supply authorities suffer from a lack of capital, since electric light undertakings involve heavy capital expenditure, and returns are a long time coming in. Company undertakings which had a reserve capital were therefore few, while municipal authorities were dependent for all large schemes on loans raised under rules laid down by the Local Government Board. It was, therefore, obvious that if the Ministry were to carry out its policy, it must be prepared to find money to finance extensions.

The question was definitely raised in September, 1915, when the Sheffield and Coventry Corporations applied for assistance towards extending their electricity works in order to meet the additional demands resulting from the munition output in their areas. As these were evidently but the forerunners of similar requests, it was considered that a general policy should be adopted with regard to them all, and the Ministry, the Treasury, and the Local Government Board in consultation drew up a scheme to serve as a basis for financial agreements with local authorities. The capital required for extension was to be lent by the Ministry at 4¾ per cent. interest for the periods usually allowed for loans for similar works by the Local Government Board. If during the period of the loan the plant was found to be more than was required for the public service of the area, the Ministry was either to take over the plant at the amount of the debt outstanding, less any profit resulting to the local authority from the installation of the plant, or write off so much of the debt outstanding as would prevent any loss to the local authority in respect of the plant. Any matters arising out of the agreement were to be settled by the Local Government Board under Section 62 of the Housing and Town Planning Act of 1909.

On the basis of this scheme the Ministry began negotiations with the Coventry and Sheffield Corporations. As, before the details of the general scheme had been settled by the Government Departments, the Ministry had mentioned 4½ per cent. as the rate of interest to these two Corporations, proposals were made on this basis, though the Treasury intimated that they would only accept this rate owing to the peculiar circumstances and that it must not be considered as establishing a precedent. The Coventry Corporation accepted the proposals without any demur, and an agreement was made on 29 September, 1915.[1] In December the agreement was extended to cover a further loan of £30,278, but the rate of interest was 4¾ per cent. instead of 4½ per cent. The Sheffield Corporation proved less easy to deal with, as they considered that the rate of 4½ per cent. was excessive. As, however, the Treasury firmly declined to make any further concession, the Corporation had to give way on this point. As an alternative, however, they inserted in the heads of agreement several stipulations with which the Ministry and the Treasury were not prepared to agree. Negotiations were therefore still further

[1] The actual text of the agreement has not been found.

protracted, and it was not till January, 1916, that terms were finally arranged. Under the agreement the Corporation was to finish the extension of the Neepsend Electric Power Station, already begun under arrangement with the Local Government Board, and equip it with the necessary machinery and plant, mains and cables. The cost of the building and the equipment originally designed for it was to be borne by the Corporation, but for all the additional machinery, mains, and cables, which had become necessary owing to the increased munitions demand, and which the Corporation estimated would involve a capital outlay of approximately £160,000, the Ministry was to advance money at 4½ per cent. interest. In addition the Ministry agreed to pay any additional cost incurred by the Corporation in pushing forward the work at the highest possible speed up to a sum of £7,500. At any time the Ministry was to have the option either of removing the equipment for which they had advanced money (subject to 12 months' notice in writing) or of requiring the Corporation to buy it at its fair market value at the time of purchase. The Corporation might at any time pay off any debt outstanding under the agreement after giving six months' notice.

In February, 1916, the Sheffield Corporation applied for another loan of £137,000 to cover the installation of further machinery, on the same terms as in the existing agreement. They based this request on the additional demands for current amounting to 14,700 kilowatts from the big munitions firms of Sheffield. Prominent among the applicants were the two National Projectile Factories, Messrs. Hadfield and Messrs. Kayser, Ellison & Co. Such a demand could not be met even when the extensions already agreed to were giving a full supply of power, and in addition there was the necessity of keeping a safe margin of power in case of emergencies. The Ministry, however, considered that the new application could not be regarded in the same light as the earlier one, since the first extension was pressed upon the Corporation to provide chiefly for the large new demand of the national factories, and urgency was the chief factor in the situation. The proposed new plant was to provide for expansion of requirements, not additional ones, and would not be available before 1917. It was thought that the Corporation ought to take the responsibility for providing plant to meet the growth of demand, and therefore the Treasury agreed with the Ministry in refusing to make special terms, and the Corporation was informed that the usual procedure of a loan raised under the sanction of the Local Government Board should be adopted.

In February, 1916, an application was received from the Bradford Corporation for a loan of £98,965 to provide for an extension of their electric power station. The Corporation wished to make an agreement on the basis of the model Treasury agreement, but the Ministry considered that it did not apply entirely to the Bradford case, since it had been drawn up to meet cases where extension was directly necessitated by output of munitions. In the Bradford area there was a large amount of textile work as well as munition work, and it was impossible to separate the demands of the non-munition trades

on the power station from those of the munition trades. At the same time it was not desirable, "from the point of view of the efficient conduct of the war,"[1] to refuse the Corporation any assistance at all. The estimated cost of £98,965 was therefore split up into two parts, £49,515, covering the extension of the boiler house and cooling tower equipment, which was the most urgent part of the work, and £49,450 for the remainder of the extensions. In a letter to the Treasury the Ministry pointed out that there was an argument for assistance in respect of this sum also, namely, that "power can be provided more economically . . . from a Central Power Station than from a number of private power plants," and that "the resulting economy of production is of undoubted value from the point of view of industrial output in an important export trade." But they did not press the point, and the Treasury only sanctioned a loan of £49,515, saying that they thought the rest of the scheme should be abandoned, because of "the strong objection to capital expenditure at the present time, to which no exception can be admitted save for the sole purpose of an immediate expansion of munitions output."[2]

Loans were granted to many other Corporations besides Sheffield, Coventry and Bradford. The Sheffield agreement may, however, be considered as typical, except that the rate of interest was 4¾ per cent. instead of 4½ per cent., and in many later agreements the stipulation appears that the Corporation shall not make any connections to their mains for supplying electricity for any purpose other than munitions making except with the express consent of the Ministry.

Financial assistance to company undertakings could not be given on the uniform lines arranged for local authorities, since the circumstances of the cases differed widely and individual treatment was therefore desirable. The broad principle adopted was that where a company could show that the increased demands on its power supply were the result of expanded munition industries, favourable consideration should be given to the proposals made by the company for Government help. As far as possible the efficiency and the ultimate value of the power station in a national system of power supply were taken into account in granting financial assistance. But it was not always possible to refuse help to badly managed or badly situated power stations, and undoubtedly many power stations were extended on account of immediate necessity which would not fit in satisfactorily to a future national system.

The terms on which assistance was granted varied considerably. A typical example is the loan granted to the Yorkshire Electric Power Company in February, 1916. The company pointed out that the demand of munition firms in the area supplied from their power station had increased abnormally since the spring of 1915, while they had been unable to increase their plant to a sufficient extent to keep pace with the demand owing to lack of reserve capital. The result was that their generating plant was loaded up to the fullest extent. Owing

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[1] Hist. Rec./R/1380/3.

[2] Hist. Rec./R/1380/3. Treasury letter of 14 March, 1916.

to the strain to which it was subjected there was constant danger of breakdowns, and new demands were coming forward which there was no possibility of meeting without the installation of new plant. It was impossible at that date to raise new capital through the usual channels, and therefore the company asked for a Government loan to meet the necessary outlay, which they estimated at £60,000. The security for the loan was to be the new plant, interest was to be at the rate of 5 per cent., and repayment was to be made in equal annual instalments in the four years following the termination of the war or earlier if the company so desired. The Ministry approved the proposal, and sanction having been obtained from the Treasury, the loan was granted on these terms.

An agreement of another type was proposed by the Clyde Valley Electrical Power Company. The demands for electrical power in the Clyde district were, by February, 1916, overtaxing the capacity of the company's two existing stations, and the erection of a third station was an urgent necessity. The company realised that this expenditure would normally have become necessary in about three years' time; but, as they pointed out, they were now being compelled to undertake it under the worst possible conditions, and the cost would be at least 50 per cent. more than under pre-war conditions, while at the end of the war the value of the station would fall by at least an equal amount. In view of the fact that the company's ordinary shareholders had received no interest on their shares during the 14 years the company had been in existence, the Directors did not feel justified in undertaking the expenditure involved unconditionally. They therefore asked the Ministry to sanction the treating of the sum of £25,000, which they estimated would be the increase on the capital cost due to war conditions, as depreciation spread over a period of three years in all questions of taxation, and that the income tax and the excess profits tax should be adjusted on these lines. Though this proposal suited the circumstances of the Clyde Valley Company, the difficulty of applying it as a general principle was that few of the electrical undertakings made excess profits. In utilising it therefore as a basis of agreement with other firms it was modified slightly, and the same object was obtained by guaranteeing to companies the difference between the war costs of carrying out extensions and the estimated cost of the same work at periods which varied from one to five years after the conclusion of peace.

One or other of these plans was usually adopted in dealing with requests for financial assistance. A few power companies asked for definite grants towards the excess cost of war extensions, but it was generally considered fair that electric supply undertakings enjoying a monoply and supplying a commodity for which there would be a large post-war demand should not be entitled to assistance to the same extent as manufacturing firms called upon to extend their factories and manufacture products for which there was normally but little demand. It is estimated that the extension of power houses and mains during the war involved a sum of £23,000,000, and of this about £3,150,000 was advanced by the Ministry of Munitions. The measures taken

during the winter of 1915-16 apparently met the immediate demand. But by the end of the year it became obvious that in certain areas further extensive provision must be made if demands which would materialise in 1917 and 1918 were to be met. In Sheffield and Birmingham especially applications for new connections were very heavy, and both Corporations therefore laid before the Ministry schemes for the erection of large new stations. These stations would be finished by the middle of 1918, and would be ready to take up the demands which, as the Corporations pointed out, would require immediate satisfaction if the war was still in progress, while if the war were over by this date they would be of the utmost value in helping to meet the heavy post-war demands for materials and manufactures of every kind. In view of the fact that these proposals were for future rather than immediate needs, it was felt by the Ministry that a question of policy was involved, and they were therefore referred by the Ministry to the Advisory Council. The Council decided that, in view of the existing shortage of raw material and labour, the Ministry ought not to use its powers to push forward schemes which would not materialise for a considerable time and which, it was hoped, would have a post-war rather than a war value. Accordingly the Corporations were informed that the Ministry could offer them no assistance, and they must proceed with their plans by the usual methods of Parliamentary legislation and negotiation with the Local Government Board. Apparently this was done by the Sheffield Corporation, since the proposed Blackburn Meadows station figures in a scheme for linking up with the Rotherham Corporation works carried out in 1917. The Birmingham Corporation seems to have dropped its scheme for a time, but it was revived again in 1918 in connection with a plan to link up with the Shropshire, Worcestershire and Staffordshire Power Company.

The logical development of concentration of supply in existing public service undertakings was the connecting up of stations situated near to one another and with similar plant equipment in order to obtain still larger units of supply. This was the policy advocated by the various committees reporting on the development of a national system of power supply after the war, and the immediate advantages to be gained were greater economy of labour and materials and less danger of failure of supply through breakdowns of generating machinery. This question of reserve power became very important as the demand increased and the difficulties of extension became greater. Many of the smaller power stations were working almost up to the limit of their power capacity, and if a breakdown occurred complete stoppage was the result. By connecting such stations with other stations a transfer of the load was made possible at a crisis and the possibilities of delaying output were minimised. For this reason specially the Electric Power Supply Department pressed the policy of linking up suitable stations in large munition areas wherever possible. The most successful example of this scheme was to be found at Rotherham. Early in the war the Rotherham Corporation extended their power station and equipped it with new plant on the most modern

lines. The machines, which consisted of two 12,500 kilowatt sets and one 25,000 set, were the largest in any generating station in Great Britain. In order to get the full value out of this plant, it was arranged that the station should be linked up with the new Blackburn Meadows Station of the Sheffield Corporation, so that 10,000 kilowatts could be transmitted either way. In November, 1917, the idea was brought forward of extending this scheme by linking up also the Yorkshire Electric Power Company's area, the South Yorkshire coalfield and the Lincolnshire ironstone area, covering in all 1,250 square miles. A committee of those interested was appointed to make proposals, and they recommended the construction of new power houses on the river Trent for the service of the whole area. No action was taken on the report, however, since obviously the scheme involved other than war considerations, and therefore must await post-war legislation covering the whole question of power supply.

It was not always easy, however, to carry out even purely war schemes, owing to difficulties experienced with the local authorities or with the Treasury. A proposal for co-operation between the British Cellulose Company and the Derby Corporation came to grief because, instead of accepting the Ministry's suggestion that similar generating sets of 6,000 kilowatt capacity should be installed by both, the Company wished to instal two 10,000 kilowatt sets in its own power house and sell current to the Derby Corporation. Though this was sound engineering policy, the susceptibilities of the Derby Corporation were offended, and in so far as the Company's proposal turned a scheme for interdependence into one of dependence of one body on the other, it ran counter to the idea of co-operation. The whole scheme was therefore dropped and each station carried on supply individually.[1]

A plan which had to be abandoned owing to financial difficulties was the establishment of a joint power supply by the Birmingham Corporation and the Shropshire, Worcestershire, and Staffordshire Electric Power Company. In January, 1918, it was proposed that a new power house should be built at Nechells containing two 15,000 kilowatt turbo-alternators, and another on the Severn at Stourport containing three similar machines. The estimated cost of the scheme was £2,750,000, and it was hoped that the entire enterprise would be completed in 21 months' time. The initiators of the scheme proposed that the Ministry should find the capital and that the Corporation and company should jointly establish a Generating Authority to work the power houses and pay an annual rent at the rate of 7 per cent. to the Ministry. The scheme was approved by the Electric Power Supply Department because both authorities were already working at their maximum load, their existing plants were in serious need of overhauling and repair, and urgent war applications for further power

[1] It appears that later the Director of Electric Power Supply modified his view, because of the soundness of the British Cellulose Company's schemes, and supported their proposition. But since urgency was the first consideration, and modification of arrangements would curtail delay, the original scheme was adhered to.

were awaiting fulfilment in both areas. It was therefore inevitable that extensions should be made by each authority, and it was much more economical for present purposes and more in line with future developments that a joint scheme should be undertaken. The scheme was endorsed by the General Services Committee of the War Priorities Committee and by the Munitions Council Co-ordinating Committee in March, 1918, but the Treasury, supported by the Board of Trade, refused to sanction it on the ground that it was not a war measure and therefore did not fall within the scope of the Ministry Vote of Credit. The Treasury considered that the action to be taken "at the moment" was to instal "the minimum plant necessary to satisfy the demand for munitions purposes in the Birmingham district in the shape of generating units of comparatively small size (5,000 to 6,000 kw.), which it would appear can be provided more readily than the larger sets and at a considerably lower initial cost." As regards the Stourport part of the scheme, it could "await consideration as part of the general problem of the reorganisation of power supply."[1] This attitude was strongly deprecated by the Director of the Electric Power Supply Department, who pointed out that, though the smaller additional provision of capacity would cover the absolute minimum stand-by requirements, a compromise of this kind would be "indefensible from the standpoint of permanent development, since it would perpetuate an inefficient system of supply and would make it impossible to utilise the available sites in an economical fashion."[2] As, however, the Treasury remained obdurate and the difficulty of getting a special Vote of Credit in Parliament seemed insuperable, the full scheme was abandoned.

(*b*) Control of Supply.

Though the most significant part of the department's activity was its extension policy, its work in controlling distribution of power and supplies of electrical equipment was by no means unimportant. At first control of equipment was adequately secured by the priority system. No certificates were issued to applicants for electrical plant without the approval of the department, and all electrical manufacturing firms had to submit their orders and obtain confirmation of their priority certificates before manufacture could proceed. Thus grading according to urgency was secured, and work other than essential war work was eliminated. A check on the distribution of power was obtained by the submission of electrical supply undertakings' schemes to the department for approval. This system worked satisfactorily till 1918, when the necessity for cutting down plant requirements to the absolute minimum, and economising in the use of power because of the coal situation, led to the establishment of a more rigid system of control.

The first order issued was the Converter Plant Control Order in April, 1918.[3] It was found that many firms, especially shipbuilding

[1] Council Committee on Demobilisation and Reconstruction, Serial No. 122.
[2] *Ibid.*
[3] Appendix XVIII.

firms, were demanding supplies of direct current from public service undertakings where alternating current was being generated. Though this was equally suitable for power purposes, no amount of persuasion would induce many consumers to use it, and money, material, and labour were being widely wasted in installing converting plant. The refusal of the Ministry to issue licences for converter plant in such cases strengthened the hands of the engineers of power stations in dealing with conservative consumers and convinced these by experience of the equal value of alternating current for power purposes.

The critical position of the coal supply rendered restrictions on the use of electric power absolutely indispensable in 1918. In July the Coal Controller suggested the possibility of rationing electric power stations as regards supplies of coal. But this course was strongly opposed by the Electric Power Supply Department, which pointed out that the consumption of coal by public service undertakings only had increased by 1,000,000 tons during 1917 and 1918, and would, it was estimated, need to be increased by a further 1,000,000 tons in 1918 and 1919 if the demands of the munitions firms for electric power were to be met. The right course to adopt was not to ration electric power supply undertakings, but to restrict the use of electricity for other than urgent war purposes by forbidding the making of new connections. A Council Committee of the Ministry was appointed to consider the position, and they recommended that Regulation 11a of the Defence of the Realm Act should be amended to cover electricity, and a control order should then be issued. They considered that the order should be widely framed, and besides prohibiting new connections should give the Ministry power to order certain classes of consumers to cease using current during certain hours of the day, to close down unnecessary power stations, and to order the interlinking of power stations and the sale and purchase of current to or from interlinked stations. The practical difficulty of devising machinery to carry out the last recommendation and the possibility of industrial disturbance involved in the first caused these recommendations to be dropped, and when the Electricity (Restriction of New Supply) Order was issued in November, 1918, it was confined to restricting the connection of new consumers to power stations to those wholly engaged upon the production of urgently needed munitions.[1]

The necessity for enforcing this Order to any great extent was avoided by the signing of the Armistice. In January, 1919, the Order was revoked, and in February the Converter Plant Control Order followed it into oblivion. In the matter of electrical supply, control was therefore practically confined to priority grading, and even here certificates were granted with considerable freedom until the increasing shortage of labour and materials made greater restrictions inevitable. In adopting this policy the department was guided by the consideration that electrical supply undertakings were doing their best to give an urgently needed supply under circumstances of considerable difficulty, and that restrictions would only hamper their activity and discourage their efforts.

[1] Appendix XIX.

(c) Advisory Functions of the Department.

In the course of its work of extending supply and controlling distribution, the Electric Power Supply Department was called upon to advise, not merely other departments of the Ministry, but also the War Office, the Admiralty, and the Air Ministry. At first the other Government Departments carried out their schemes and placed their orders independently. But as soon as demand outdistanced supply, this procedure was bound to lead to conflict at the centre, and irritation and unequal burdens locally. Accordingly it was arranged that all Supply Departments, both Ministry and otherwise, should consult the Electric Power Supply Department on all schemes where the installation of electric generating plant or the purchase of current from a public service undertaking was concerned. Schemes for Admiralty shipyard extensions involving the use of electric power were also placed before it. On the financial side it assisted the Local Government Board and the Scottish Office by advising on the technical aspect of municipal applications to borrow money for electrical extensions.

(d) Supplies to Allies.

Advice on the requirements of Allied countries also formed part of the department's work, and in the case of Russia, it had also to undertake a good deal of the responsibility for supply. In the earlier part of the war, the Russian Government and Russian firms were large buyers of electrical machinery and apparatus from Great Britain. Much of this plant appears to have been ordered without any co-ordinated plan, and this, combined with the sinking of some most important cargoes of power station equipment, made it a difficult matter to meet the Russian demands effectively. When Russia withdrew from the war there was a great deal of plant still in various stages of manufacture for her. As far as possible orders were cancelled, but it was better policy to complete some of it and adapt it to British requirements. At the date of the Armistice, however, a great deal of it still remained in hand.

A certain amount of help was also given to America to erect generating stations at the American bases in France. The department sent engineers to France to consult with the American authorities and much of the plant was supplied from England.

III. Increased use of Electricity during the War.

(a) Developments in Industry.

A survey of the developments in the electrical industry during the war indicates its possibilities as one of the most potent forces in the industrial world. Both the quantity of power demanded and the new uses to which it was put prove its significance as a factor in rapid and economical output. The most interesting and important development was the adoption of electrical furnaces for producing steel, particularly in the Sheffield district and at Woolwich Arsenal. Before the war a

large percentage of Sheffield's tool and other steel was produced by smelting a high grade ore imported from Sweden. At the outbreak of war these ores were diverted to Germany, and English steel makers had to supply the deficiency from other sources. Experiment showed that the same class of steel could be produced from scrap metal, and from iron and steel obtained from home and Spanish ores, by means of electrical furnaces. So successful was this treatment that in 1918 there were 117 furnaces in existence (74 were situated in Yorkshire), very few of which had been installed before the war.

Under Lord Pirrie's régime as Controller of Merchant Shipbuilding at the Admiralty, there was a large development in the use of electrically driven compressors in shipyards. Lord Pirrie thought that the installation of these compressors, with which very few of the shipyards were as yet furnished, was the key to more rapid shipbuilding construction, and about 80 compressors were put in hand for various shipbuilding centres. Another device for hastening shipbuilding was the use of electricity for welding ships' plates. This was, however, only in the experimental stage at the end of 1918.

Schemes were also set on foot for an improved type of electric regenerator for the testing of aeroplane engines which could be used with alternating current instead of direct current. It was estimated that this new equipment would effect such economy as to pay for itself within a few years. Unfortunately the time that must elapse before the new plant could be manufactured, the doubt as to the future policy of the Air Board, and the conservatism of manufacturers, all combined to discourage an active forward policy, and when the Armistice was signed the idea was dropped, though it would appear to be of as great value in normal industry as in war time production.

(*b*) Expansion of Electric Power Supply.

The remarkable acceleration of output during the war can only be realised by examining the statistics for the period 1914 to 1918. One hundred and forty-six stations were either extended or built,[1] and many stations which did not extend their buildings increased their plant. In June, 1914, the plant capacity of 557 municipal and company stations was 1,135,000 kilowatts ; in November, 1918, it was 2,278,000, having thus doubled itself during the four years.[2] As individual examples of expansion Sheffield and Rotherham may be instanced. Sheffield's plant capacity in 1914 was 23,000 kilowatts, in 1918 it was 96,000. Rotherham is even more remarkable. From 5,000 kilowatts the capacity of the Corporation station rose to 70,000, an increase of 1,300 per cent. Not only was the total capacity of the plant affected, the size of the generating unit also increased. The average size of the unit installed before the war was 522 kilowatts, and the largest unit in operation was 8,000 kilowatts. At the end of the war the average size was 7,000 kilowatts, and units as large as 25,000 and 30,000 kilowatts were being built. Output rose to correspond with the increase in

[1] Appendix XVII. [2] *Ibid.*

capacity. During the year ending June, 1914, the units sold were 2,100,000. For the year 1917 they were 3,520,000, and though actual data were not available, it was estimated by the Electric Power Supply Department that the 1918 output was nearly double that of 1914. Sheffield alone increased its output about 6½ times; in 1914 the units sold were 26,500,000, in 1918 177,500,000. This increased output was obtained side by side with a decreased consumption of coal. The coal consumption per unit was in 1914 4·1 lb.; in 1918 it was only 3·75 lb., in spite of the relative inferiority of the fuel at that date. This was due largely to the more efficient plant, the improved load factor of many power stations, and the extended use of oil fuel, waste heat and gas and water power for generative purposes. During the years 1914 to 1918, 288,000,000 units were obtained by these means.

The great interest of the organisation of the electric power supply during the war lies in its relation to post-war conditions. Unlike much of the industrial development promoted by the Government during the war, its value has not decreased with the return to peace conditions. The policy of centralisation of power production advocated unanimously by the committees appointed to consider the part to be played by electric power in reconstruction is to be found in germ in the practice of the Ministry, and experience of war production has proved that only in this way can the generation of electricity be undertaken at a reasonable cost and in sufficient quantities for it to be available throughout the country as the normal motive power in industry. Not only has the experience of the Ministry been of value to the State as the starting point of a scheme for the general application of electric power to industrial conditions; the leaders of industry themselves are following in its steps in advocating the use of electric power on co-operative principles. A noteworthy instance of this is that the Yorkshire and Lincolnshire centralised power supply scheme brought forward by the Ministry in 1917 is now being seriously considered by the industrial organisations of the area with a view to taking action when the necessary legislation has been passed. This is but a forerunner of many similar schemes, and even if a national scheme of electric power supply does not become an accomplished fact, industry as a whole has been so convincingly shown by Government enterprise the value of electricity in accelerating and cheapening production that development along these lines will be an essential part of the industrial organisation of the future.

APPENDICES.

APPENDIX I.

(CHAPTER I., p. 17.)

Specimen Authorisation to Contractor to Put Work in Hand.

Armament Buildings,
Whitehall Place,
London, S W.

Sir,

GAUGE ORDER.

You are authorised to put in hand immediately the gauges enumerated on the attached list.

The gauges must be delivered to the order of :—

D.G.M.S., c/o Director,
National Physical Laboratory,
Teddington, Middlesex.

It is desirable that the first gauge of every pattern should be sent to the laboratory to be tested before the order is completed.

Arrangements have been made with the N.P.L. to secure their assistance in the checking of the gauges, and it is suggested that you would be well advised to have check gauges, and such fundamental length standards as you may require to use in the manufacture of the gauges, standardised at the laboratory before completing your work.

Material should be tool or high grade steel, with hardened working surfaces ; screw gauges, with certain exceptions, need not be hardened.

Every gauge must be marked, in accordance with the list attached, with the following particulars :—

Description of parts to be gauged.

Dimensions of gauging parts.

Identification or I.L.S. Number.

Initials of Contractor.

Serial Number.

Date (month and year only).

Note.—Each gauge must be stamped with a different serial number ; if the series allotted is 51 W. to 100 W. the first gauge of the order will be marked 51 W., the second 52 W., and so on, to the end of the series.

In flat gauges the shapes may be altered provided the gauging dimensions on the drawings are adhered to.

Four small holes may be drilled for punching so as to machine several at one time, also small clearance holes may be drilled in corners to facilitate grinding.

Female, cylindrical and screw gauges having two gauges in the one piece of metal may be fitted with steel bushes driven in and finished to size if preferred.

The contract and official order for this work will follow in due course ; material, however, should be ordered and work put in hand at once.

Official working drawings will be supplied by the Chief Inspector, Woolwich.

I am, Sirs,

Your obedient Servant,

SCHEDULE.

Gauge Order Number	G.O. 370.
Class of Gauge.	Inspection
Gauges required for	Cartridge Q.F. 18-pounder Mk. I and II.
Drawing No. of Gauges.	C.I.W. 2038

Delivery, 8 weeks from date of receipt of official working drawings.

Quantities and types required :—

100 Gauges I.L.S. 272 C. Screw Gauge, Primer Hole (to be hardened).

Gauges to be stamped as follows :—

Identification No. Initials. Serial Nos.

APPENDIX II.

(CHAPTER I., p. 22.)

Illustrations of Downward Tendency of Prices.

Type of Gauge.	*Date of Contract.*	*No. ordered.*		*Contractor.*	*Price per Gauge.* £	s.	d.
Shell 8in. How. 981D.	28.3.16	25	..	Horstmann Cars, Ltd.	4	0	0
	2.6.16	12	..	Flottmann Eng. Co.	3	17	6
Shell 6in. H.E. 413E.	17.11.15	12	..	G. Cussons, Ltd. ..	12	0	0
	23.12.15	12	..	Wildt & Co. ..	7	15	0
	13.9.16	1	..	Wildt & Co. ..	6	7	6
Shell 4·5in. How. 42E.	25.10.15	6	..	Ackworthie & Co. ..	12	0	0
	13.9.16	1	..	Wildt & Co. ..	6	7	6
Shell 18-pdr. H.E. 617C.	11.15 5.12.15 23.1.16	50 200 175	..	Triumph Cycle Co...	1	16	0[1]
	15.12.15	25	..	Horstmann Cars, Ltd.	1	15	0
	15.10.16	1	..	Boulton & Paul ..	1	10	0
	15.10.16	1	..	Hans Renold & Co.	1	10	0
Shell 18-pdr. H.E. 899C.	21.10.15	50	..	British Thomson-Houston Co. ..	2	10	4
	18.11.15	50	..	Robert Scaife ..		17	0
	15.1.16	150	..	Gamble & Co. ..		12	6
Shell 13-pdr. H.E. 689C.	2.11.15	20	..	British L. M. Ericsson Co.	2	8	11
	22.12.15	1	..	Tilling-Stevens, Ltd.		10	0
	14.1.16	30	..	Riley Engine Co. ..		8	9
Rifle Gauges No. 277	16.9.15	6	..	Stokes & Co. ..		15	0
	15.6.16	10	..	T. Watson		9	6
Rifle Gauges No. 1051	14.12.15	40	..	Larkins & Bailey ..	1	5	0
	4.4.16	18	..	Larkins & Bailey ..		18	0
	20.9.16	27	..	Larkins & Bailey ..		16	6
Primer Percussion 639C.	25.11.15	25	..	Wolseley Motors, Ltd.	3	0	0
	30.12.15	6	..	Pitters Eng. Co. ..	2	10	0
	31.5.16	200	..	Bassett Lowke, Ltd.	2	2	0
Gaine 393E... ..	9.8.15	50	..	Imperial Typewriter Co		18	6[2]
	21.9.15	20	..	Muir & Co. ..	2	12	0
	20.1.16	50	..	Earth Driven Clock Co.	2	8	0
	14.3.16	70	..	Earth Driven Clock Co.	2	8	0[3]

[1] R.L. price on October 1, 1915, was £1 14s.
[2] Gauges made at this price not satisfactory.
[3] Order and Supply Lists. Supplements 3 H., 7 H., 11 H.

APPENDIX III.

(CHAPTER I., p. 23.)

Number of Gauges Tested Weekly at the National Physical Laboratory, 1916, 1917 and 1918.[1]

Date.		*Check Gauges.*		*Screw & Profile Gauges.*		*Total of all types dealt with.*	
1916.		*Tested.*	*Passed.*	*Tested.*	*Passed.*	*Tested.*	*Passed.*
January ..	(4)[2]	77	47	605	275	3,332	2,375
February ..	(4)	120	80	842	497	4,435	3,217
March ..	(4)	72	55	1,010	612	3,195	2,262
April ..	(5)	64	40	950	650	2,624	1,988
May ..	(4)	65	42	845	570	3,150	2,365
June ..	(4)	77	55	930	552	4,155	3,177
July ..	(5)	120	84	1,066	654	4,495	3,398
August ..	(4)	105	82	1,500	962	4,965	3,905
Sept. ..	(5)	122	80	1,128	734	4,574	3,564
October ..	(4)	105	77	1,104	930	4,670	3,530
November	(4)	112	70	1,337	880	4,692	3,460
Dec. ..	(5)	238	120	1,310	832	5,532	4,336
1917.							
January ..	(4)[2]	160	105	1,230	785	6,735	5,077
February ..	(4)	180	135	1,870	1,200	8,782	6,255
March ..	(5)	172	118	1,970	1,314	9,444	7,398
April ..	(4)	202	145	1,672	1,122	8,652	6,707
May ..	(4)	152	80	2,337	1,552	10,032	7,560
June ..	(5)	238	144	2,072	1,350	8,612	6,674
July ..	(4)	115	77	3,072	2,227	11,015	8,367
August ..	(4)	150	87	2,067	1,442	9,835	7,285
Sept. ..	(5)	156	94	3,066	2,248	10,400	7,720
October ..	(4)	162	97	2,835	1,955	9,820	7,352
Nov. ..	(4)	145	90	3,050	2,097	9,840	7,017
December	(5)	148	122	2,970	2,286	9,210	6,694

1918.		*Check.*		*Screw.*		*Form & Profile*		*Total of all types dealt with.*	
		Tested	*Passed*	*Tested*	*Passed*	*Tested*	*Passed*	*Tested*	*Passed*
Jan. ..	(4)[2]	111	66	2,414	1,759	572	325	8,000	5,769
Feb. ..	(4)	145	105	2,717	1,840	418	257	7,131	5,012
Mar. ..	(5)	146	83	2,846	1,842	278	167	6,474	4,366
April ..	(4)	98	65	3,238	2,364	209	137	6,473	4,689
May ..	(4)	142	93	2,409	1,792	263	177	5,927	4,280
June ..	(5)	127	94	2,810	2,015	189	155	7,230	5,257
July ..	(4)	77	49	2,265	1,693	135	81	6,260	4,458
Aug. ..	(5)	63	39	2,052	1,632	174	111	5,780	4,389
Sept. ..	(4)	74	46	2,549	1,983	174	127	6,329	4,816
Oct. ..	(4)	117	79	3,006	2,512	160	130	6,621	5,174
Nov. ..	(5)	102	65	2,497	1,940	144	127	5,478	4,098
Dec. ..	(3)	84	60	2,528	1,954	58	33	4,757	3,486

[1] This does not represent the total output of gauges, since all rifle gauges are tested at Enfield Lock, and gun gauges and certain gun ammunition gauges are tested at Woolwich (*see* pp. 32 and 35). The table is prepared from charts supplied by the Gauge Department. The figures are only approximate.

[2] Number of weeks in month.

APPENDIX IV.

List of Technieal Reports and Papers dealing with Gauges, etc.

1. "Limit Gauges," by Sir R. T. Glazebrook. (*Engineering*, 8 and 15 September, 1916.)
2. Three articles on Gauge Measuring and Equipment at the National Physical Laboratory. (*Engineering*, 16, 23 and 30 August, 1918.)
3. Leaflet *re* Hoffmann Rollers. (D.A.O./G.8A, issued by Ministry of Munitions, 7 September, 1916.)
4. "Notes on Screw Gauges," by the Gauge Testing Staff of the National Physical Laboratory. (Published by H.M. Stationery Office.)
5. Paper on "Screw Thread Measurement," read before the Liverpool Engineering Society, 10 January, 1917, by Arthur Brooker.
6. Paper on the "Manufacture of Gauges," read before the Institution of Mechanical Engineers at the L.C.C. Paddington Technical Institute.
7. Report on British Standard Fine (B.S.F.) Screw Threads and their tolerances (No. 84) by the British Engineering Standards Association.
8. Gauge Making and Lapping. (Machinery's Ref. Series No. 64.)
9. Hardening and Tempering. (Machinery's Ref. Series No. 46.)
10. Screw Thread Cutting. (Machinery's Ref. Series No. 32.)
11. Screw Thread Tools and Gages. (Machinery's Ref. Series No. 31.)
12. Article in *American Machinist* of 20 December, 1917, on "The Inspection of Screw Gages for Munitions of War," by H. J. Bingham Powell.
13. Verification of Gauges at the National Physical Laboratory. (G.C.4, issued by the Ministry of Munitions, 9 October, 1916.)

APPENDIX V.

(CHAPTER II., p. 41.)

Constitution of Advisory Committees on Machine Tools.

1. CONSTITUTION OF THE MACHINE TOOL ADVISORY COMMITTEE.

(*a*) *July*, 1915.

Mr. Alfred Herbert (Chairman).
Provost W. B. Lang (Vice-Chairman, Scotland).
Mr. J. W. S. Asquith (Yorkshire and District).
Mr. W. F. Clark (London, Birmingham, Bristol, etc.).
Mr. W. D. Ford-Smith (Lancaster and District).
Mr. G. H. Churchill (Importers).
Mr. E. M. Iliffe (Secretary).

(*b*) *November*, 1918.

Provost W. B. Lang (Chairman) Mr. J. W. S. Asquith (Vice-Chairman) Sir Alfred Herbert, K.B.E. Mr. E. M. Griffiths Mr. L. H. Ransome Mr. W. D. Ford-Smith	Representing the Machine Tool Trade.
Sir Richard Cooper, Bart., M.P. (Finance Department) Mr. E. M. Iliffe (Controller, Machine Tool Department) Mr. J. W. Milne (Contracts Department and Prices Section) Mr. J. D. Steven (Small Tools Section) Mr. L. G. Wykes (Secretary)	Ministry of Munitions.

2. CONSTITUTION OF THE SMALL TOOL ADVISORY COMMITTEE SEPTEMBER, 1918.

Mr. E. M. Iliffe (Chairman).

Mr. H. Arnison Mr. A. Balfour Mr. J. H. Barker Mr. S. H. March Mr. P. McGregor Mr. J. Neill Mr. W. S. Skelton Mr. Pye Smith	Representing the Small Tool Trade.

Sir Richard Cooper, Bart., M.P. Mr. S. R. Judd Mr. J. W. Milne Mr. J. D. Steven	Representing the Ministry of Munitions.

Mr. L. G. Wykes (Secretary).

3. Constitution of the Merchants and Importers' Advisory Panel, September, 1918.

Mr. E. M. Iliffe (Chairman).

Mr. F. M. Burns Mr. T. S. Catmur Mr. A. L. Churchill Mr. A. Denton Mr. W. Hatch Mr. A. T. Parry Mr. J. Pickin Mr. E. A. Savage Mr. T. W. Simpson Mr. J. T. Stuart Mr. L. H. Turtle	Representing the Merchants and Importers.
Mr. F. E. Bagnall Sir Richard Cooper, Bart., M.P. Mr. J. W. Milne	Representing the Ministry of Munitions.

Mr. L. G. Wykes (Secretary).

APPENDIX VI.

(CHAPTER II., p. 47.)

War Office Circular to Machine Tool Contractors.

War Office,
London, S.W.,
May, 1915.

GENTLEMEN,

I am commanded by the Army Council to inform you that, in order to expedite work on completion of contracts for the supply of munitions of war, which are urgently needed for our armies in the field, it is necessary that supplies of all machine tools, presses or other similar appliances in the country should be made immediately available for the manufacture of such munitions of war.

I am to instruct you accordingly to divide all the orders relating to the articles above mentioned in progress at your works at

or elsewhere, and also all other such orders that you may have on your books, into two classes as shown below :—

A.

Orders for British and Allied Governments ;

Orders for British and Allied Armaments Companies ;

Orders for Contractors and sub-contractors to the above, in cases where the orders are for use on Government contracts or sub-contracts ;

Orders for British Colonies or for India, in cases where you have actual knowledge that the orders are for direct or indirect use in the production of munitions of war.

B.

Orders for neutral countries, whether or not covered by the prohibition order referred to below ;

Orders for British Colonies or for India, in cases where you have no actual knowledge that the orders are for use in production of munitions of war ;

Orders for British firms for machinery which is not to be used directly or indirectly in the production of munitions of war.

As regards delivery under your contracts, you are hereby instructed to give preference to Class A before Class B. Moreover, wherever earlier delivery of orders in Class A can be given by diverting or suspending orders in Class B, you are directed so to divert or suspend, and this without regard to any contracts or obligations you may be under in respect of orders in Class B.

All future orders which would come under Class B are to be accepted only on the understanding that they are liable to suspension, diversion and delay, and that they cannot in any case be executed so long as you have similar orders unexecuted in Class A, even if such orders in Class A are of later date.

Your attention is called to the following extract from the Defence of the Realm (Amendment) Act :—

> " It is hereby declared that where the fulfilment by any person of any contract is interfered with by the necessity on the part of himself or any other person of complying with any requirement, regulation, or restriction of the Admiralty or the Army Council under the Defence of the Realm Consolidation Act, 1914, or this Act, or any regulations made thereunder, that necessity is a good defence to any action or proceedings taken against that person in respect of the non-fulfilment of the contract so far as it is due to that interference."

and to Regulation 8a of the Defence of the Realm Consolidated Regulations as follows :—

> " It shall be lawful for the Admiralty or Army Council (*a*) to require any work in any factory or workshop to be done in accordance with the directions of the Admiralty or Army Council, given with the object of making the factory or workshop or the plant or labour therein as useful as possible for the production of war material ; (*b*) to regulate or restrict the carrying on of work in any factory or workshop or remove the plant therefrom, with a view to increasing the production of war material in other factories or workshops, and the occupier and every officer and servant of the occupier of the factory or workshop, and where the occupier is a company, every director of the company, shall obey the directions, regulations, or restrictions of the Admiralty or Army Council so given, and if he fails to do so he shall be guilty of an offence against these regulations."

and to the following Order in Council under date of 26 April, 1915 :—

> " That the following articles should be added to the list of goods the exportation of which is prohibited to all foreign ports in Europe and on the Mediterranean and Black Seas, other than those of France, Russia (except Baltic ports), Spain and Portugal :—
>
> " Raw cotton.
>
> " Metal working machinery."

I am to request that you will forward at once an acknowledgment of the receipt of these instructions to Machine Tool Department, Cecil Chambers, 76, Strand, London, W.C.

This letter has been addressed simultaneously to all the firms whose names are in the attached schedule.

I am,
Gentlemen,
Your obedient Servant,
R. H. BRADE.

APPENDIX VII

(CHAPTER II., p. 48.)

Ministry of Munitions Circular to Machine Tool Contractors.

Ministry of Munitions,
6, Whitehall Gardens, S.W.
24 *July*, 1915.

GENTLEMEN,

The Army Council, by an Order dated May, 1915, instructed you to divide all orders for machine tools into two classes, "A" and "B," and instructed you to give precedence to Class "A."

A subsequent Order of the Army Council further instructed you to accept no orders for machine tools, except for British and Allied Governments, their Contractors and Sub-Contractors, without the express permission of the War Office, and further instructed you to make certain returns as to work in progress.

In view of the continued heavy demands for machine tools for the manufacture of munitions of war, it has now become necessary for the Minister of Munitions, in the exercise of the powers conferred on him by the Ministry of Munitions Act, 1915, and by the Ministry of Munitions Order, 1915, and with the assent of the War Office, to assume more complete control over the machine tool trade of the country.

I am therefore to instruct you that, from this date, you are to accept no orders for machine tools from any Government, person, or persons whatsoever, other than the Minister of Munitions (or such Department or Departments of the Ministry of Munitions as the Minister may authorise), the Admiralty, or the Army Council, except with the express consent of the Minister of Munitions (or such Department of the Ministry of Munitions as aforesaid).

I am further to instruct you that you may, at the discretion of the Minister (or of such Department as aforesaid), be required from time to time to suspend or divert any work of any description which you may have in progress, or to cancel any orders which you may already have received.

I am,
Gentlemen,
Your obedient Servant,
H. LLEWELLYN SMITH.

APPENDIX VIII.

(Chapter II., p. 50.)

Prohibition of Importation of Machine Tools.

GEORGE R.I.

WHEREAS by Section forty-three of the Customs Consolidation Act, 1876, it is provided that the importation of arms, ammunition, gunpowder or any other goods may be prohibited by Proclamation.

And whereas it is expedient that the importation into the United Kingdom of machine tools and parts thereof, excluding small tools, should be prohibited as hereinafter provided:

Now, Therefore, We, by and with the advice of Our Privy Council, in pursuance of the said Act and of all other powers enabling Us in that behalf, do hereby proclaim, direct and ordain as follows:—

As and after the 21st day of December, 1915, subject as hereinafter provided, all machine tools, and parts thereof, excluding small tools, shall be prohibited to be imported into the United Kingdom.

Provided always, and it is hereby declared, that nothing in this Proclamation shall apply to machine tools and parts thereof, imported under the licence of the Board of Trade and subject to the provisions and conditions of such licence.

This Proclamation may be cited as the Machine Tools (Prohibition of Import) Proclamation, 1915.

Given at Our Court at Buckingham Palace, this thirtieth day of November, in the year of our Lord one thousand nine hundred and fifteen, and in the Sixth Year of Our Reign.

GOD SAVE THE KING.

APPENDIX IX.

(CHAPTER II., p. 60.)

Control of Sale and Purchase of Machine Tools.

28 *August*, 1916.

In pursuance of the powers conferred upon him by Regulation 30 (A) of the Defence of the Realm (Consolidation) Regulations 1914, the Minister of Munitions hereby orders that the war material to which the Regulation applies shall include war material of the following classes and description, namely :—

All machine tools and machinery driven by power and suitable for use in cutting, stamping or working metal, including :—

Lathes.
Milling machines.
Drilling machines.
Planers.
Grinding machines.
Boring and turning mills.
Power presses.
Punching and shearing machines.

Shapers.
Screw machines.
Chucking machines.
Boring machines.
Slotting machines.
Forging machines.
Cutting-off machines.
Gear-cutting machines.
Centring machines.

NOTICE OF GENERAL PERMIT UNDER THE ABOVE ORDER.

28 *August*, 1916.

The Minister of Munitions gives notice (1) that he hereby permits all persons until further notice to purchase or enter into negotiations for the purchase of the war material referred to in the above Order Provided that such purchase or negotiations are from or with persons holding a special permit from the Minister to sell such war material and not otherwise ; (2) that he hereby permits the insurance of any such war material.

All applications for a special permit in connection with the above Order should be addressed to the Director of Machine Tools, Armament Buildings, Whitehall Place, London, S.W.

APPENDIX X.

(CHAPTER II., p. 51.)

Control of Sale and Purchase of Wood-working Machinery.

5 *June*, 1917.

In pursuance of the powers conferred upon him by Regulation 30a of the Defence of the Realm Regulations, the Minister of Munitions hereby orders that the war material to which that Regulation applies shall include war material of the following classes and descriptions, namely :—

All machinery driven by power and suitable for use in cutting, working, or operating on wood, including :—

Sawing machines of all descriptions.
General joiners.
Mortise, tenon and boring machines.
Lathes and rounding machines.
Box and cask-making machines and all machines accessory thereto.
Scraping and sandpapering machines.
Wheelwright machinery.
Firewood-making and bundling machinery.
Wood wool fibre and pulp machinery.
Saw-sharpening and setting machines.
Saw stretchers and brazing apparatus.
All machines for grinding, planing or moulding irons.

NOTICE.

All applications for a permit to purchase or enter into negotiations for the purchase of the war material referred to in the above Order should be made to the Executive Officers of the Area Clearing House Boards, whose addresses may be obtained upon application to " The Director, Central Clearing House, Ministry of Munitions, Charing Cross Buildings, S.W. 2."

All applications for a permit to sell or enter into negotiations for the sale of the war material referred to in the above Order should be made to " The Director of Wood-working Machinery, Charing Cross Buildings, S.W. 2."

APPENDIX XI.

(CHAPTER II., p. 53.)

Control of Manufacture of Small Tools.

10 *May*, 1918.

The Minister of Munitions in exercise of the powers conferred upon him by the Defence of the Realm Regulations and all other powers thereunto enabling him hereby orders as follows :—

1. No person shall on or after the 1st day of June, 1918, until further notice, manufacture any small tool as hereinafter defined, or any part thereof, except under and in accordance with the terms of a licence issued under the authority of the Minister of Munitions.

2. Every person engaged in the manufacture of Small Tools shall make such returns with regard to his business as shall from time to time be required by or under the authority of the Minister of Munitions.

3. For the purposes of this Order the expression "Small Tools" shall mean all or any Engineers' or Machinists' small tools and shall include the following :—

Abrasive Wheels.
Adjustable Clamps.
Auger Bits.
Band Saws.
Boring Heads.
Callipers.
Chasers.
Chucks.
Circular Saws.
Dial Gauges.
Dies and Die Stocks.
Die Heads.
Drills.
Drill Sleeves and Sockets.
Emery Wheel Dressers.
Expanding Mandrels.
Expansion Bits.
Files.
Furniture and Dovetailed Bits.
Gauges.
Hacksaw Blades.
Hand and Breast Drills.
Hand Grinders.
Hide Hammers.
Lathe Carriers.
Lathe Dogs.
Lead Hammers.
Machine Vices.
Measuring Tapes and Rules of all descriptions, including Verniers.
Micrometers.
Milling Cutters.
Pipe Cutters.
Pipe Vices.
Pipe Wrenches.
Pliers.
Punches.
Reamers.
Screwing Tackle (*i.e.*, Chasers, Dies and Stocks, Taps and Thread Milling Cutters).
Swage Shapers.
Tapping Attachments.
Taps.
Tap Wrenches.
Tool Holders.
Tube Expanders.
Wood Boring Bits.

4. All applications for licences under this Order shall be addressed to the Controller of Machine Tools, Charing Cross Buildings, London, W.C. 2, and marked "Small Tools."

5. This Order may be cited as the Small Tools Order 1918.

APPENDIX XII.

(Chapter II., p. 58.)

Deliveries and Imports of Machine Tools during 1918.[1]

Date.	Value of Machine Tools (including Small Tools).		Machine Tool Imports.	
	Sanctioned Monthly.	*Delivered Monthly.* £	*In Tons per Month.*	
January	1,231,645	1,046,315	3,360	Out of total imports for 1918, 38,853 tons, 38,478 came from America.
February	1,083,468	796,268	1,589	
March	877,280	551,912	1,895	
April	1,301,575	842,705	2,701	
May	905,908	729,200	5,174	
June	959,096	938,476	3 804	
July	1,015,405	1,079,215	4,136	
August	1,051,784	815,868	4,010	
September	1,123,360	831,228	2,515	
October	1,467,595	1,004,670	3,249	
November	—	—	2,573	
December	—	—	3,847	

[1] The only figures available for 1916 and 1917 are those for sanctions, the average monthlv value of which is given on p. 58.

APPENDIX XIII.

(CHAPTER II., p. 68.)

Labour in the Machine Tool Trade.

	Men.	*Women.*	*Total.*
January, 1916	41,173	1,096	**42,269**
January, 1917	33,142	3,259	**36,401**
June, 1917	32,450	3,904	**36,354**
January, 1918	22,800	6,200	**29,000**
July, 1918	20,300	6,600	**26,900**
September, 1918	20,800	6,700	**27,500**

APPENDIX XIV.

(CHAPTER III., p. 77.)

Control of Manufacture, Sale and Purchase of Ball Bearings.

1 *November*, 1917.

The Minister of Munitions in exercise of the powers conferred upon him by the Defence of the Realm Regulations and all other powers thereunto enabling him HEREBY ORDERS as follows :—

1. No person shall on or after the date hereof until further notice manufacture any ball bearing or roller bearing (both of which are hereinafter included in the expression "ball bearing"), or any part thereof except under and in accordance with the terms of a licence issued under the authority of the Minister of Munitions.

2. No person shall on and after the date hereof until further notice sell, supply or deliver any ball bearing or any part thereof whether situated in or outside the United Kingdom, or purchase or negotiate for the purchase or take delivery of any ball bearing or any part thereof situated outside the United Kingdom except under and in accordance with the terms of a licence issued under the authority of the Minister of Munitions.

3. All persons engaged in the manufacture or sale of ball bearings shall make such returns with regard to their businesses as shall from time to time be required by or under the authority of the Minister of Munitions.

Note.—All applications in reference to this Order should be addressed to the Director of Ball Bearings, T.M. 3, Ministry of Munitions, Whitehall Place, London, S.W. 1, and marked "Ball Bearings."

APPENDIX XV.

(CHAPTER III., p. 86.)

Progressive Increase in Output of Ball Bearings from Home Factories.

Firm.	Period. 4th quarter, 1916. Average per month.	4th quarter, 1917. Average per month.	Sept. to Nov., 1918 Average per month.	Estimated output on completion of extensions.
Hoffmann Co.	87,490	117,794	160,720	172,000
Skefko Co.	20,000	31,246	25,540	80,000
Ransome and Marles ..	6,262	9,690	18,827	25,000
Electric Ordnance Accessories Co.	5,183	5,541	6,150	8,000 ?
Rudge Whitworth, Ltd. ..	—	—	6,488	80,000
Auto Machinery Co. ..	8,422	9.252	10,280	10,000 (No extension)
Mair, Nixon and Ferguson..	318	693	1,265	2,000 ?
Total	127,675	174.216	229 270	377,000

APPENDIX XVI.

(Chapter III., p. 90.)

Total Supplies of Ball Bearings from November, 1917, to October, 1918 (including American).

	Home Supplies.		Overseas Supplies.		Total.
		%		%	
1917.					
November	189,060	56·9	142,973	43·1	332,033
December	161,693	57·4	120,156	42·6	281,849
1918.					
January	188,468	39·7	286,051	60·3	474,519
February	179,678	50·2	178,236	49·8	357,914
March	180,835	37·9	296,867	62·1	477,702
April	175,228	62·4	105,654	37·6	280,882
May	188,105	40·8	273,259	59·2	461,364
June	184,734	50·3	182,438	49·7	367,172
July	201,993	57·9	146,988	42·1	348,981
August	120,357	49·4	123,378	50·6	243,735
September	203,598	56·4	157,343	43·6	360,941
October	313,576	64·6	171,918	35·4	485,494
Monthly average	190,610	51·2	182,105	48·8	372,715

APPENDIX XVII.

(CHAPTER IV., p. 105.)

Principal Electric Power Supply Undertakings Increasing their Capacity between 1914 and 1918.

I.—MUNICIPAL UNDERTAKINGS.

(*a*) Stations above 5,000 kilowatt capacity in 1914 which doubled their capacity (approximately).

Corporation.	*Plant Capacity at 30 June, 1914.*	*Additional Plant installed or authorised between 30 June, 1914, and 31 October, 1918.*
	Kilowatts.	*Kilowatts.*
Aberdeen	8,380	9,380
Battersea	5,092	5,000
Birmingham	33,000	51,650
Bolton	7,600	10,900
Bradford	16,800	27,450
Coventry	12,000	13,200
Derby	7,050	7,500
Glasgow	54,900	99,050
Greenock	11,900	21,100
Leeds	22,940	33,660
Oldham	5,340	7,050
Rochdale	5,476	5,780
Rotherham	5,150	65,350
Salford	8,500	9,500
Sheffield	23,225	73,000
Stepney	7,720	9,480
Swansea	5,100	5,000
Wolverhampton	7,050	16,450

(*b*) Stations above 5,000 kilowatt capacity which extended but did not double their capacity.

Corporation.	*Plant Capacity at* 30 *June*, 1914.	*Additional Plant installed or authorised between* 30 *June*, 1914, *and* 31 *October*, 1918.
Belfast	13,300	10,500
Brighton	12,100	4,000
Bristol	15,050	9,000
Bury	5,700	3,000
Cardiff	8,200	3,000
Edinburgh	17,980	2,500
Halifax	7,500	5,500
Hampstead	5,889	1,500
Huddersfield	7,450	4,000
Hull	10,210	5,000
Leicester	7,450	6,000
Liverpool	*37,000	*10,000
L.C.C. Tramways	38,500	9,000
Manchester	72,300	46,450
Newport	7,100	3,000
Plymouth	5,475	4,800
Poplar	10,000	4,250
St. Pancras	8,850	3,000
Shoreditch	5,680	5,000
Southampton	5,500	3,000
Sunderland	8,500	7,500
Stalybridge	18,000	1,000

* Mersey Power Company extended from 4,900 to 24,500.

II.—Company Undertakings.

Stations above 5,000 kilowatt capacity in 1914 which extended their capacity.

Company.		
Central Electric	26,283	7,570
Charing Cross	23,480	3,000
City of London	27,000	6,000
Clyde Valley	35,000	37,500
Cornwall	6,745	3,000
County of London	19,800	14,400
Kensington and Knightsbridge	9,390	500
Lancashire Electric	16,500	6,000
London Electric Supply	25,450	12,000
Metropolitan	22,500	4,000
Midland Electric	10,600	10,200
Newcastle-upon-Tyne and Associated Companies.	86,200	114,200
Newcastle and District	9,000	8,000
North Metropolitan	16,122	21,068
Shropshire, Worcester and Staffs	28,325	15,850
South Metropolitan	6,000	15,000
South Wales	10,500	5,000
Trafford	5,200	7,950
Yorkshire Electric	14,300	12,200

APPENDIX XVIII.

(CHAPTER IV., p. 102.)

Control of Purchase, Manufacture and Installation of Electric Converter Plant.

5 *April,* 1918.

The Minister of Munitions in exercise of the powers conferred upon him by the Defence of the Realm Regulations and all other powers thereunto enabling him hereby orders as follows :—

1. No person shall on or after the date hereof until further notice purchase or manufacture, or erect or instal in or in connection with any factory, workshop, steel works, shipyard, colliery or other premises for the purposes of which alternating current is or can be made available, any rotary converter plant, motor generator plant or converter plant of any description for transforming alternating current to direct current, or any part of such plant (all or any of which shall be included in the expression "converter plant") except under and in accordance with the terms of a licence issued on behalf of the Minister of Munitions by the Director of Electric Power Supply.

2. Nothing herein contained shall prevent the carrying out of any necessary repair to converter plant already installed at the date hereof, or the purchase, manufacture, erection or installation of converter plant required solely for electro-chemical or electrolytic processes or electric traction.

3. All applications in connection with this Order shall be made to the Director of Electric Power Supply, Ministry of Munitions, 8, Northumberland Avenue, W.C. 2.

4. This Order may be cited as the Converter Plant Control Order, 1918.

Note.—The licence required by this Order is in addition to and not in lieu of the usual Priority Certificates and permit reference number.

Applicants for licences are warned against purchasing or installing direct current motors before the licence for the necessary converter plant has been obtained.

APPENDIX XIX.

(CHAPTER IV., p. 103.)

Control of Electricity Supply.

8 *November*, 1918.

The Minister of Munitions in exercise of the powers conferred upon him by Regulation 11a of the Defence of the Realm Regulations and all other powers thereunto enabling him hereby orders as follows :—

1. No person shall on or after the date hereof except under and in accordance with the terms of a permit issued under the authority of the Minister of Munitions :—

(*a*) Connect or cause to be connected to any source or means of supply of electricity any place or any building, premises or plant or any part thereof not so connected at the date hereof, or

(*b*) Supply or cause to be supplied any electricity to any place or any building, premises or plant or any part thereof not supplied with electricity at the date hereof, or

(*c*) Use or cause to be used any electricity in or at any such place, building or premises or for the purpose of any such plant as hereinbefore mentioned.

PROVIDED that in any case coming within the scope of the Household Fuel and Lighting Order, 1918, or the Household Fuel and Lighting (Scotland) Order, 1918, as defined by Clause 1 of these Orders respectively, where the previous assent of the Local Fuel Overseer is required and has been duly obtained to any fitting, equipment or supply under Clause 99 of the first mentioned Order or Clause 77 of the secondly mentioned Order, no permit hereunder shall be required for such fitting, equipment or supply or the use of such supply.

2. All applications with reference to this Order should be addressed to the Director of Electric Power Supply, Ministry of Munitions, 8, Northumberland Avenue, London, W.C. 2.

3. This Order may be cited as The Electricity (Restriction of New Supply) Order, 1918.

Note.—The permission required by the Order is in addition to and not in lieu of the usual Priority Certificates and permit reference number.

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VOLUME VIII

THE CONTROL OF INDUSTRIAL CAPACITY AND EQUIPMENT

PART IV

CONTROL OF ENGINEERING CAPACITY: ADMINISTRATIVE MACHINERY

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Control of Engineering Capacity: Administrative Machinery.

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PART IV.

CONTROL OF ENGINEERING CAPACITY: ADMINISTRATIVE MACHINERY.[1]

I. Introduction.

Among the many vital problems facing the Ministry at its inception were the relative claims of local autonomy and centralised control from headquarters. It was obvious from the beginning that such a vast organisation as was contemplated by Mr. Lloyd George would necessitate a certain measure of administrative devolution. The proper utilisation of hitherto untouched industrial resources, the assistance and encouragement of new firms, the introduction of improved methods of manufacture, and the adaptation and installation of new equipment and machinery, all required close supervision, together with a generous freedom of adaptability to varying local circumstances. Yet local autonomy brought with it the dangers of misdirected effort, overlapping administration, conflict of aim, lack of uniform procedure, and financial extravagance. The choice thus lay between the Scylla of over-great centralisation and the Charybdis of too much local independence; success in producing the much-needed munitions depended upon the skill of the helmsman in keeping a middle course between the two.

II. Area Office Organisation with Superintending Engineers.[2]

A solution was sought in the creation of the administrative machinery known as Area Organisation. It was at first contemplated that in addition to the headquarters organisation established at Whitehall, branch offices of the Ministry would be established in each of the ten areas into which the United Kingdom was to be divided. The original intention was that each Area Office should form an administrative unit with an officer at its head entrusted with the responsibility of taking action within the limits of general policy determined at headquarters. Each Area Office would have a Secretary, a Superintending Engineer, and a Labour Officer. In the original scheme for the organisation of the Area Offices the Secretary was indicated as the responsible officer, but later the Superintending Engineer became the head, and the Secretary acted as his subordinate. The Superintending Engineer was to deal with all matters arising from every branch of munitions production within the area,[3] while a Labour

[1] Hist. Rec./H/1126/1; Hist. Rec./H/1600/10; Hist. Rec./H/263.71/3; Hist. Rec./H/1500/6; Hist. Rec./R/1710/1, 2, 5, 6; Hist. Rec./H/1200/6.

[2] A full account of the work of the Area Office under the Department of Area Organisation will be found in Vol. II, Part II.

[3] Except trench warfare supplies, which had local officers from the very beginning outside and independent of Area Organisation. (*See below, p.* 3.)

Officer was to control similarly the supply of labour within the area.[1] These three officers and their staff were to be the link between local firms and headquarters, advising the latter in the placing of orders by means of their local knowledge, and placing the collective experience of all areas at the disposal of the former in order to obtain the greatest possible production. In so far as the Area Offices were to be permitted a good deal of independence in assisting firms in the actual performance of contracts, it was expected that this organisation would conduce to speed and economy in output; while the fact that policy would be dictated from headquarters and all orders for the supply of different classes of munitions within the area would go through a single channel would produce balance of supply and co-ordination of effort.

The principle behind this scheme is clear and simple. Unfortunately its applicability in practice was limited by the circumstances of the time and the interests and energies of the men who were to work the scheme. For these reasons the scheme was difficult to carry out with logical balance and completeness. In 1915 the output of empty shell was the most urgent preoccupation of the Ministry, and consequently from the first the energies of the Area Offices were concentrated on the task of speeding up the output of shell. The Superintending Engineer, instead of being an impartial local representative of all headquarters departments, became largely identified with the Department of Shell Manufacture. In consequence, other departments began to appoint their own staff for local purposes who were responsible only to their own departmental head at headquarters, though if their work lay in a definite area they generally used the Area Office as their local centre. In consequence of this virtual supersession of the centralised directing authority of the Superintending Engineer within the area, the evils of conflicting jurisdiction, multiplication of officials, and absence of co-ordination began to appear.

To understand the position of the Superintending Engineer, it must be borne in mind that his functions theoretically continued to be comprehensive and he still remained the principal representative of the Ministry of Munitions in the area. Broadly speaking, his task was to obtain full knowledge of all the engineering possibilities of the district and develop its resources for munitions manufacture as fully as possible on lines laid down from time to time by the Ministry. His advice and assistance were freely at the disposal of individual contractors. He was the chief authority in the district on the use of machinery, and in many cases exercised a concurrent authority with the Labour Officer with regard to the use of skilled labour. He had to advise the Ministry as to the capacity of firms to carry out proposed contracts and as to the possibilities of sub-contracting and of establishing new types of engineering industry in the area. In addition, he had to keep a watchful eye on the general progress of manufacture, assisting firms to instal labour and power-saving devices and aiding them to overcome obstacles which threatened to hinder

[1] Hist. Rec./H/1121/6; Hist. Rec./H/1121/2.

production. It is easy to see that, with such a broad charter, the possibilities of conflict with the representatives of individual departments were many, and as the tendency for departments to set up their own outside staff increased, the position of the Superintending Engineer became more and more invidious. If he carried out his duties to the full extent laid down, he found his work continually overlapping, if not actually in conflict with the work of other officials; if, on the other hand, he limited his functions to the shell shops he lost the comprehensive outlook and command necessary for co-ordination of effort throughout the industry.

The position had an equally bad influence on the manufacturing firms in the area. They found different departments competing for their capacity, and the temptation to play off one against another was almost irresistible. Moreover, they were harassed by the visits of numerous officials whose instructions and requirements were often irreconcilable and who frequently appeared to duplicate each other's enquiries. Though time and experience brought some amelioration and adjustment, the growing pressure of war necessity prevented the establishment of any satisfactory equilibrium. From the chronic impasse thus created a radical reorganisation offered the only means of escape. It was the realisation of this necessity that led to the proposal to establish a Department of Engineering in the latter part of 1917.

Some slight measure of co-ordination between these multifarious local inspection and progress authorities was brought about by the fact that when practicable the local officials of all the Ministry of Munitions supply departments were housed in the Area Offices. This was an obvious advantage from the point of view of the manufacturer, who grew to regard the Area Office as the centre of information on every point, and it made communication and co-operation between the different local staffs easier. But in so far as these different officials were under no real local control, the Area Office became an agglomeration of units instead of an organisation with interdependent parts, and thus the original idea of the Area Office disappeared under the pressure exercised by individual supply departments at headquarters.

Before turning to the history of this development it is necessary to consider briefly the other branches of the Ministry exercising local control which were in existence before the end of 1917, since the Department of Engineering was created by the absorption of these and the Area Offices into one comprehensive organisation.

III. Some other Forms of District Organisation.

(a) Outside Engineering Branch of the Trench Warfare Supply Department.

The most important as well as the oldest of the departmental local organisations was the Outside Engineering Branch of the Trench Warfare Supply Department. The nucleus of this branch was in

existence before the Ministry was established, being a part of the War Office organisation concerned with the supply of trench warfare materials. When this became a function of the Ministry of Munitions, the existing department was taken over as a whole, and therefore the Outside Engineering Branch automatically became part of the organisation of the Ministry and from the first stood outside the scheme of local administration embodied in the Area Organisation machinery. The Outside Engineering Branch was entirely controlled by the Trench Warfare Supply Department in London, and until October, 1915, its staff worked in the provinces without any recognition whatever of the existence of the Area Office. It was the regular channel for communication between the Trench Warfare Supply Department and its contractors. Its functions were to inspect and select suitable works for the manufacture of trench warfare supplies, to assist manufacturers in every possible way with advice and encouragement, to help in obtaining materials and machinery, and to push on manufacture as rapidly as possible.

The lack of co-ordination between the Trench Warfare Supply Department and the Department of Area Organisation resulted not merely in competition and conflicting instructions to manufacturers, but also in the failure of trench warfare officers to obtain complete information regarding the progress of trench warfare contracts placed with Boards of Management. In the autumn of 1915 efforts were made to co-ordinate the activities of the two departments. From this time onwards senior members of the Outside Engineering Branch, under the name of Trench Warfare District Engineers, were located in nine areas,[1] and were assisted by junior engineers known as Trench Warfare Supervisors. They were instructed to co-operate with the Area Engineers to prevent overlapping in the placing of contracts. While the District Engineers were to continue to recommend suitable firms for contracts to the Trench Warfare Supply Department, the actual placing of orders was to take place through the Department of Area Organisation, which was to be kept fully advised of all impending trench warfare requirements. Once the contract was placed, supervision of progress was to remain in the hands of the Trench Warfare District Engineers.

This arrangement failed to secure its end for two reasons. It conflicted with the established policy of the Trench Warfare Supply Department, which had always been based on the principle that, inasmuch as the manufacture of trench warfare material was in a constant state of change, direct control over contractors was absolutely necessary for proper supervision. Moreover, large exceptions were made in the application of the rule as to placing orders through the Area Organisation Department. It was recognised that firms with whom the department had already placed contracts when the arrangement was made must continue to be dealt with directly. In practice

[1] These areas were Newcastle, Manchester, Leeds, Birmingham, Newport, London, Edinburgh, Glasgow, and Ireland.

this exception covered so many contractors that it almost nullified the agreement. In every area it was found that the Trench Warfare Supply Department could continue to place the majority of its contracts without any reference to the Department of Area Organisation.

Further negotiations were set on foot to remedy the situation. It was first proposed that the Trench Warfare Supply Department should be placed under the direct control of the Director-General of Munitions Supply on an equal footing with the other supply departments, when its local engineers could be absorbed into the staff of the Area Offices. But the peculiar problems of trench warfare supply afforded a strong argument against such a procedure, and eventually it was decided to retain the Trench Warfare Supply Department as a separate entity, and to modify the agreement already come to. The Trench Warfare Supply Department was still to have the right to deal directly with existing contractors, but all fresh or repeat orders with such firms were to be placed through Boards of Management. In placing such contracts a statement of requirements and all pertinent particulars were to be sent to the Area Organisation Department, which would then obtain from the Boards of Management a list of firms suitable for undertaking the work. The selection would be made by the Trench Warfare Supply Department on the advice of the Trench Warfare District Engineers ; the order would be placed through the Board of Management, and a notification would be sent to the Department of Area Organisation. The actual administration of the contract would be carried out by the Trench Warfare Supply Department, whose outside engineering staff would still visit and assist progress, acting in harmony with the Area Organisation officials. This arrangement was found more satisfactory, and after some experiment and modification, the system was put into regular working. It was found that about 80 per cent. of the contracts were placed through Boards of Management, the remainder being experimental or peculiarly difficult contracts which it was essential should be placed directly by the Trench Warfare Supply Department.

(*b*) Inspection and Progress Section, Mechanical Warfare Department.

Another example of an independent body of inspecting engineers is to be found in the organisation set up by the Mechanical Warfare Department, which was concerned with the production of tanks. This is of interest because in this case the Ministry entrusted the responsibility for inspection and supervision of progress to the same body of men. In most departments responsibility for acceptance and responsibility for stimulating output were in different hands: the outside engineers or progress inspectors (by whichever name they were called) had no power of passing the finished article: this was done by the staff of the Chief Inspector at Woolwich. The most noteworthy exception, when the Mechanical Warfare Department adopted this system, was the Mechanical Transport Department,

which had been transferred from the War Office in September, 1916, and continued to rely upon its inspecting officers to hasten progress, in accordance with arrangements of some length of standing. From January, 1917, until the autumn of 1918, in the Mechanical Warfare Department the same staff undertook both duties. The Inspection and Progress Section was divided into two parts. The headquarters staff included the Chief Progress Officer who received the reports of the Divisional Inspectors; the Chief Metallurgist, under whose care was the laboratory for testing metals and the heat treatment of steel for armour plate; and other specialists to whom reference could be made by manufacturers or by the Divisional Inspectors. In November, 1918, there were outside Production Officers for engines and spares, components, and armour plate supply. In addition the headquarters staff dealt with all problems of standardisation, interchangeability, shortages, and other matters requiring uniform treatment throughout the country. Local organisation was on the district basis. Certain large towns were chosen as the centres of areas, at the head of which were Divisional Inspectors. In all there were seven areas—London, Lincoln, Birmingham, Manchester, Sheffield, Leeds, and Glasgow. Each area was a self-governing colony. There was no overlapping between the areas and no interference with the authority of the Divisional Inspector from headquarters. Unity in the work of the department was attained by the general direction of district activity by the Chief Progress Officer and by periodical conferences between the Divisional Inspectors and the headquarters staff.

Like the Outside Engineering Branch of the Trench Warfare Supply Department, the Inspection and Progress Section of the Mechanical Warfare Department was entirely independent of the Area Office staff and thus another overlapping local organisation was created.[1] The Divisional Inspectors endeavoured, however, to keep in touch with the area machinery as far as possible, attending the meetings of the Area Organisation Boards and working in harmony with the Superintending Engineers.

(c) Ordnance Engineers.

A further example of the development of the specialised local representative to watch progress after the formation of the Area Organisation is to be found in the institution of Ordnance Engineers. These were attached to the Department of Gun Manufacture, and were appointed about the end of 1917. Thus they were a comparatively late development, and seem to have been the direct result of the experience gained in other departments. Over two years of close supervision of shell manufacture by means of the Superintending Engineer and his staff had brought the industry to a high state of

[1] A comparison will show that the area divisions did not coincide. In this the Mechanical Warfare Department differed from the Trench Warfare Supply Department which utilised the existing area divisions for the location of their District Engineers.

efficiency, and had also brought about very considerable economy in manufacture. It was argued, therefore, that a similar organisation would benefit gun manufacture, and from a departmental point of view the argument was sound. But from the point of view of the whole activity of the Ministry, the appointment of Area Ordnance Engineers added another set of officials to increase the congestion already manifesting itself. The Ordnance Engineers were stationed at Manchester, Newcastle, Barrow, Glasgow, Coventry, Erith, and Southampton, and supervised the progress of gun manufacture around these centres. These areas did not coincide with the areas under the Area Organisation scheme any more than did those of the Mechanical Warfare Department, and this created considerable difficulty when later the amalgamation of the engineering staffs under the Department of Engineering was proposed.

(*d*) Gas Engineers.

In order to facilitate the recovery of benzol and toluol in gas works a system of district inspection was established early in 1915. The country was divided into seven areas, each with a representative gas engineer. The areas were then sub-divided into districts which were placed in charge of supervising engineers, whose work was to assist the gas companies to obtain the largest possible amount of toluene from the gas.[1]

IV. Travelling Progress Officers.

Turning to the second form of local control, that exercised from headquarters by means of travelling officers, who were experts in their particular branch of work, the earliest and most complete example is to be found in the Explosives Supply Department.

(*a*) Inspectors of the Explosives Supply Department.

The development of local inspection in this branch of supply was largely empirical at the start, owing to the way in which the Department of Explosives Supply developed out of Lord Moulton's Committee on High Explosives and became first a department of the War Office and then a department of the Ministry of Munitions. The necessity for organisation for local inspection arose from the dangerous and technical character of the manufacture. When the High Explosives Section was formally established in the department of the Master General of Ordnance in January, 1915, a staff of expert travelling inspectors was appointed under the control of the Chief Chemist, Dr. R. C. Farmer. The business of these chemists was to encourage standardisation of process, to inspect materials during the process of manufacture, to arrange for an adequate supply of war materials,

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[1] *See* Vol. VII, Part IV, Chap. II.

and to assist firms undertaking the manufacture for the first time. By March, 1915, this organisation of travelling chemists reporting directly to headquarters was in full working order, and when the Explosives Supply Department came under the control of the Ministry of Munitions the organisation was retained. The Explosives Inspectors were in no way connected with the Area Organisation, but were throughout attached entirely to headquarters.

(b) Machine Tool Inspectors.

Another example of the system of travelling inspectors is the organisation set up by the Machine Tool Department. These inspectors were all attached to headquarters, and were sent to different parts of the country as necessity dictated. To the usual duties of assisting manufacturers to increase output and of advising the departments as to available capacity was added in their case the duty of seeing that machine tool firms complied with the rules laid down by the department under the different orders controlling the trade. Thus their work went beyond the mere attainment of efficiency in production; they were the channel by which the department controlled the trade and regulated the flow of machinery to meet the urgency of demand from the great munition industries.

(c) Travelling Inspectors of other Departments.

The organisations set on foot by the Explosives Supply Department and the Machine Tool Department are typical of the scheme for local inspection gradually developed by all important departments. Wherever the introduction of new firms into an industry was made necessary by the unprecedented demand or wherever the output of old firms needed to be improved, it became necessary for a supply department at the Ministry to introduce a form of progress inspection. In controlled trades this organisation also provided a means of preventing the evasion of the regulations. As time went on, not only output, but also economy of production and utilisation of every available reserve of labour and material became an essential part of the great munitions effort throughout the country, and the system of inspection already established served this end also. It would be tedious to enter into detail with regard to every industry, since the ends, and the means adopted to further the ends, were broadly speaking the same.

Since these travelling officials visited firms that were probably already under the general supervision of the Area Engineer and were possibly being visited for specific contracts by other local officials the burden laid upon the manufacturer grew heavier as each department organised its own outside staff, and practical experience brought home to headquarters the necessity for making some effort to end independent departmental organisation and to create a common service department which should serve all supply departments, and yet be under some central controlling authority.

V. The Central Clearing House.

(a) ESTABLISHMENT OF THE CLEARING HOUSE, OCTOBER, 1916.

A tentative attempt to attain this end in the utilisation of manufacturing capacity is to be seen in the establishment of the Central Clearing House. The supervision of the use of machinery was one of the functions of the Superintending Engineer, but his work was limited to the proper use of the machinery in his area: he had little information as to what use was being made of machinery in other areas, and no power to move machinery from one area to another. The result was that frequently there might be many contractors with idle machinery in one area, while from others demands were pouring in to the Ministry for new machinery to fulfil new contracts. The desirability of creating some form of co-ordinating agency was apparent. By placing contracts where spare capacity existed or by transferring idle machines in one area to meet demands in another the pressure on the machine tool makers might be lessened, and at the same time economy of labour and material would be secured. Such a system could only be successful if the controlling agency had detailed knowledge of the spare capacity in the country as well as of the prospective requirements of the principal Government Departments for new capacity. Knowledge of spare capacity could only be obtained through the Area Organisation, and knowledge of prospective requirements necessitated a close touch with headquarters. If an organisation could be created which would bring together the information regarding machinery obtained by the area staffs and place it at the disposal of the supply departments a valuable co-ordinating link would be obtained, and the disastrous effect of local separatism would be overcome.

A proposal for the institution of an Advisory Bureau was the subject of a memorandum by the Director-General of Munitions Supply (Sir Frederick Black) in July, 1916. In his opinion the bureau should have two functions. It ought to advise purchasing departments as to the existence of spare capacity to meet their requirements, and to arrange, through the Machine Tool Department of the Ministry, for the transfer of machine tools from places where they were lying idle. It should be presided over by a man with commercial experience, who would be assisted by a committee representing the Admiralty and the War Office Contracts departments, the Air Service, and the Ministry of Munitions. This committee would be in no sense an executive body, it would have advisory functions only, suggesting directions in which contracts might be placed, but not interfering in any way with the freedom of action of the supply department.

This proposal does not appear to have been acted upon in its entirety: for the actual organisation which was created in October, 1916, differed from it in important particulars. The organisation was to be known as the Central Clearing House. The Director and Deputy Director were to be assisted by an Advisory Board of Heads of Departments at the Ministry, and the Admiralty and the War Office were

to be asked to co-operate. The Central Clearing House was to collect information as to the distribution and use of all existing machinery, and to register idle or partly idle machinery. Demands for new machinery were to be referred by the Machine Tool Department to the Central Clearing House, which would determine how far such demands could be met by existing plant. The Clearing House would also collect information of second-hand machinery not employed on war work. Under this scheme the Clearing House was empowered to deal simply with machinery, not with engineering capacity as a whole. The original idea seems to have been that whatever organisation was created should exercise considerable powers of direction before the placing of contracts: the new procedure resulted in the practice of supply departments choosing firms to carry out contracts, and then applying to the Machine Tool Department for machinery, while the Machine Tool Department in its turn applied to the Central Clearing House to know if any machines could be moved to meet the need.

The idea of a central body to give guidance to supply departments in the placing of contracts appears again, however, in the discussions on the establishment of the Department of Engineering in 1918. Thus the Central Clearing House falls into position as a link between the unco-ordinated individualism of the earlier period of the Ministry's activities and the effort to attain co-ordination and direction which characterises its general policy in 1918. If it be borne in mind that the Central Clearing House as it was actually established was only part, and the less important part really, of a much larger scheme it would appear that the struggle which took place between opposing policies in 1918 was really preceded by a similar though milder one in 1916. At this earlier date the party which stood for the unchecked right of the supply departments to place contracts wherever they would won the day. Nevertheless, the logic of events re-opened the question in a more acute form about a year later, and the Department of Engineering rather than the Central Clearing House represents the idea originated by Sir Frederick Black.

(*b*) Organisation and Work of the Clearing House.

Besides the Central Clearing House at headquarters, Area Clearing Houses were established. An Area Clearing House was located in each of the Area Offices, and an Area Executive Board was set up consisting of the Superintending Engineer, the District Engineer of the Trench Warfare Supply Department, and the Secretary to the Area Office. In addition an area liaison officer was appointed by the Central Clearing House from among the engineers of the Trench Warfare Department, and he, together with the Secretary of the Area Office, did the actual work involved in the tracing and registering of machinery for which the Area Executive Board was responsible.

The successful working of the scheme depended largely on the degree of co-operation which could be attained between the supply departments, the Machine Tool Department, and the Central Clearing

House, at headquarters. At the outset the Director of the Central Clearing House laid down several points of policy which it was essential to carry out. The supply departments must agree to avoid placing contracts with firms who would require new machinery to carry them out and must get an assurance from the contractor that neither he nor his sub-contractors would require new machinery. Failing this assurance, the Clearing House must be applied to in order to ascertain if other facilities were available. Secondly, the Machine Tool Department must supply the Central Clearing House with particulars of new machinery on order or demand, refer to the Clearing House before releasing machine tools, and link up its existing machinery for registering second-hand tools with that of the Clearing House. Finally, the Clearing House must have regular forecasts of the approximate requirements of supply departments and a return of contracts about to be placed or to be extended. In addition to this procedure at the centre, the Area Clearing Houses must trace and register all machines in each area either by means of information supplied by engineering firms themselves or by using the visiting engineers and inspectors of all Government Departments. Co-operation in this respect was important if registration was to be rapid, detailed, and correct. In order to avoid congestion it was laid down that as much decentralisation as possible was to be established. The Area Board might negotiate immediately and on its own responsibility the transference of machines within its area, in the same way as the Superintending Engineer had formerly done. For removal of machinery from one area to another it was necessary to work by way of the Central Clearing House, but careful and detailed procedure was laid down to avoid delay at headquarters.

(c) ABSORPTION INTO THE DEPARTMENT OF ENGINEERING, FEBRUARY, 1918.

In spite of the careful organisation thus established, the Clearing House system was only a partial success. That it did succeed in utilising a great deal of idle machinery is undoubted: that it did not succeed in bringing requirements and spare capacity into any real relation to one another is equally clear. From the first the supply departments did not co-operate as they should have done, the majority of them continued to place contracts whether or not the contractor had the machinery, and this necessitated either new machinery or an enormous amount of unnecessary transference. The inevitable result of this was congestion, and by 1918 the complaints of delays occasioned by the Clearing House system were frequent. Information was not given to the Clearing House as it should have been, and thus the orderly system which was originally planned degenerated into a mere scramble to meet immediate demands. The system broke down equally in the areas. The Central Clearing House complained of the lack of local control and co-ordination of the activities of the numerous local staffs of the different departments of the Ministry which resulted in the failure to obtain the co-operation which had been stated to be

essential at the beginning of the scheme. As time went on, it became increasingly apparent that the Clearing House organisation would have to be either reformed or abolished. In February, 1918, it was decided that the Central Clearing House should be absorbed in the projected Department of Engineering, and that the Area Clearing Houses should be reorganised as part of the local activity of the new department. As a separate organisation, therefore, the Clearing House ceased to exist.

VI. The Department of Engineering.

The first suggestion for the formation of the Department of Engineering appears at the end of 1917 in the form of a memorandum from the Labour Supply Department, drawing attention to the fact that dilution was handicapped by the shortage of skilled men, and that the skilled men available were being wastefully employed by the irresponsible and unscientific distribution of contracts resulting from the uncontrolled and unco-ordinated efforts of the various supply departments. By that time all the evils inherent in the system of independent departmental activity in the areas had come to a head, and official interference with industry in the country had become a chaos which was apparent, not only to the Ministry and the manufacturers concerned, but also to the commercial world generally. This is shown clearly in a memorandum addressed to the Minister of Munitions by the Association of Chambers of Commerce in November, 1917, in which they pointed out that the diversity of control which permitted competitive purchasing "did not make for economical and efficient material production." In view of the great military effort which the Germans were known to be preparing for the spring of 1918, and of the fact that more then three years of warfare had considerably depleted the country's reserves of material and labour, this efficient national production had become the supreme necessity, and even before the memorandum of the Chambers of Commerce reached the Ministry, it was felt that some steps must be taken to improve the existing state of affairs.

(*a*) Allocation of Contracts Committee, October, 1917.

In October, 1917, the Minister of Munitions (Mr. Churchill) appointed a committee "to consider the best means of allocating contracts for supplies so as to ensure that the contracts are placed with those firms who are best able, with their existing sources of labour and machinery, to provide the output required."

In the discussions of the committee two very sharply contrasted points of view soon became apparent.[1] While all members agreed that an Engineering Efficiency Department was desirable they disagreed on the extent of the power which such a department should exercise, *i.e.*, whether it should be advisory in character or have large executive

[1] Memorandum to Minister by Sir Graham Greene, 1.12.17.

powers. On the one hand it was argued that supervision of production necessarily implied responsibility for output, and that the new department must, therefore, take over the existing functions of the supply departments and the technical officers responsible for directing output. This bold proposal was championed by Sir Glynn West. Other members of the committee considered that production and output could be clearly separated both in theory and in practice. Into the province of the former fell the scientific selection of firms, the efficient use of machinery, and the judicious employment of skilled and semi-skilled labour, while the latter could be secured by the energy, capacity, and business qualities of the administrative departments. Production considered the effective capacity of contractors as a whole to meet the varying needs of supply; supply was concerned with the output obtained on individual contracts under the conditions laid down by the Department of Production. Supply was, therefore, rather complementary to production, not included in it, and there was no reason why the two functions could not be exercised by different organisations. The group of members holding this view argued for the retention by the supply department of certain of their technical staff with responsibility for output, while establishing a Production Department which should take over those engineers with general rather than specialised functions, such as the staff of the Clearing House and the Area Organisation. Such a department would be supervisory rather than executive in character. It would collect information and arrange the placing of contracts according to the resources available and through its local organisation it would give contractors general assistance in promoting efficiency of manufacture without being responsible for actual output on definite contracts.

Another point of difference was whether the effective power of the new department should be concentrated at headquarters or decentralised among whatever local organisation it might be decided to set up. Those members of the committee who wanted responsibility for output as well as production argued also for centralised control: their scheme was the establishment of a strong department at headquarters with wide executive powers which would use local organisation merely as a channel for carrying out its policy. Other members of the committee opposed this scheme partly from the fear that such a department would tend to become a huge supply department, and partly because they thought that too great centralisation would defeat the whole object of the scheme, and that efficiency could best be secured by allowing considerable autonomy to the local organisation with its detailed knowledge of local conditions and its possibilities of immediate action. According to this view the headquarters organisation would be a body for co-ordinating the work of the officers in the country on the lines of the existing Area Organisation Department. A further reason for advocating this scheme was that by it the co-operation of the War Office, the Admiralty, and other Government Departments would be more likely to be secured, and since the support of all Government Departments was essential to the ultimate success of the scheme this was a consideration of no small importance.

(b) Report of the Committee.

It was found extremely difficult to reach any common ground. Eventually, however, a *modus vivendi* was obtained by the suggestion that a beginning might be made with an Efficiency Production Department which would be a step in a natural development without carrying out the larger scheme to the full extent immediately. A compromise was reached whereby, though considerable powers of action would be vested in local officials, decisions involving a veto on the proposals of supply departments would be reserved to headquarters. The measure of agreement thus obtained became the basis of a draft report in which the majority concurred. The report recommended the establishment in the Ministry of an Engineering Efficiency Department, which should be an additional common service department on the same footing as existing common service departments such as Design, Contracts or Finance, and which should stand in the same relations to the supply departments as these did. The Engineering Efficiency Department should be responsible for ensuring that contracts were "so placed and executed in the Works that by means of the machinery available and the smallest amount of skilled labour necessary the maximum output would be obtained." For this end the department would determine the allocation of machine tools, as well as the need for and nature of any new extensions to factories, and would give technical advice to contractors. To carry out these functions the department would be placed in charge of a Member of the Munitions Council specially responsible. The headquarters organisation would consist of a Controller to whose staff would be transferred some of the engineers employed in the supply departments, the Central Clearing House and the technical branch of the Labour Dilution Department. The outside organisation would consist of the field staff of the engineers at present reporting to the supply department and the Central Clearing House, under the control of a Chief Engineer who would be appointed to each of the different areas and who would work in close co-operation with the Labour Dilution Officer of the area.

(c) Effect of the Report on the Existing Organisation.

One of the strongest practical objections offered to the large scheme put forward by Sir Glynn West was that it would cut right across the existing organisation and necessitate a thorough re-arrangement of Ministry procedure at a time when all efforts should be directed towards obtaining the maximum output of munitions. In advising a modified scheme the committee aimed at reducing reorganisation to a minimum and hoped that the existing machinery of the supply departments would be very little disturbed. Each supply department was to retain all its existing responsibility for placing the contract, procuring drawings, providing raw materials, securing priority, arranging for labour and other requirements, and generally for the detailed supervision of the individual contract. The Engineering

Efficiency Department was simply to advise where the most suitable capacity was to be found, and during the course of the contract formulate from the returns obtained by the supply department statistics of efficiency as regards labour and machine capacity, by which means they would direct the efforts of their local engineers to the progressive improvement of productive methods and equipment. When extensions were necessary the Engineering Efficiency Department was to suggest which firm's plant was most suitable for extension and put forward a scheme, but the supply department would carry on the negotiations.

The problem of fitting in the local organisation of the new department to the existing Area Organisation was more difficult, but here again the principle was followed of making the least disturbance possible. The areas, area officers, and area secretary were to remain unchanged, and the local representatives of all departments other than supply departments would have their local headquarters as before in the Area Offices and be directed from headquarters at London. But all the local representatives of supply departments, together with the engineers of the Central Clearing House, were to be grouped together under a Chief Engineer in each area, who would be responsible to the Engineering Efficiency Department, but would be at the service of any supply department requiring local assistance which could correspond directly with the Chief Engineer if necessary.

This scheme was a compromise between the two divergent points of view. While leaving the supply departments their progress staff at headquarters, it removed from their control their local engineering staff; yet at the same time they were to continue to use those staffs for local purposes. Apparently therefore the local engineers were in the position of having to serve two masters. Moreover, it appeared to leave the contractor in the position of being open to visits from two sets of engineers, the Engineering Efficiency Department engineers for giving him advice for general efficiency, and the technical inspectors of the supply department, who might be sent down from headquarters to supervise an individual contract, if the department preferred this method to using the Engineering Efficiency Department's local staff. Locally, therefore, the scheme put forward in the report did but little to remove one of the gravest defects of the existing position. At headquarters also the report failed to carry out to any marked extent the views of those who advocated a strong executive control. The relative positions of the supply departments and the Engineering Efficiency Department under the new scheme reduced the latter to a purely advisory body with no authority to enforce its wishes as to the placing of contracts. The report of the committee necessitated the abandonment of the bolder and more progressive policy, and among other modifications which preceded the introduction of the scheme, the idea of making the Engineering Efficiency Department a common service department to the whole Ministry was abandoned for the time.

(d) Constitution and Functions of the Department.

It was thus under distinctly unfavourable circumstances that the Department of Engineering struggled into being. In March, 1918, the constitution of the department was announced. All the outside engineering staff of the departments within the Ordnance Group,[1] including the Outside Engineering Branch of the Trench Warfare Supply Department, were to form part of the staff, and the outside engineering staff in each area would constitute the Area Engineering Board, which would be responsible for the work hitherto carried out by the Area Clearing House Boards. The work of the Central Clearing House was also to be incorporated. The new organisation was to be the source of information within the Ministry on the technical aspects of ordnance production, and on the manufacturing programmes of the supply departments of the Ordnance Group. It was to prepare proposals for the interchange of machines and buildings in order to use capacity to the best advantage, and all the functions of the Central Clearing House with regard to the transference and release of machine tools were to come within its province. In addition it was to investigate cases of low efficiency, delays in delivery and other production problems at the request of the supply controllers, to advise how to improve production and to cut down supply where necessary with the least disturbance.

The limitation of the department to the Ordnance Group involved serious disadvantages, since it meant that all supply departments not within that group would continue to maintain their local staffs within the areas, independently of the organisation of the Department of Engineering. Thus the centralised local control which it was the object of the new arrangement to procure would largely disappear. This difficulty was particularly obvious in the case of the Machine Tool Department, whose organisation in the areas had overlapped considerably with the Clearing House system, and this had been a source of considerable friction in 1917. So long as the Machine Tool Department remained outside the Ordnance Group, there seemed little hope of minimising the friction. Accordingly it was decided in May, 1918, to bring the Machine Tool Department within the Ordnance Group. Automatically the Machine Tool Inspectors should then have been transferred to the staff of the Engineering Department. But it was not till July that the Machine Tool Department could be prevailed upon to waive its objections and accept the logical result of the step taken in May. Again the Ordnance Engineers, though within the Ordnance Group from the start, were not absorbed into the engineering staff till December, 1918, the objections of the Controller

[1] The Ordnance Group of departments within the Ministry comprised, in March, 1918, the Department of Gun Manufacture, the Gun Ammunition Manufacture Department, the Department of Gun Ammunition Filling, the Small Arms and Machine Guns Department, the Small Arms Ammunition Department, the Trench Warfare Supply Department, the Gauges Department, the Timber Supplies Department, the Central Clearing House, and the Department of Area Organisation.

of Gun Manufacture having taken ten months to overcome. In such circumstances it can be seen that the work of forming the Engineering Department was an uphill task. At its formation, in spite of the statement that it would include all the outside staff of the supply departments within the Ordnance Group, practically the only ones which it controlled were the Outside Engineers of the Trench Warfare Department, and the Area Clearing House Engineers. The drawing in of the Machine Tool Inspectors represented a step forward, and the inclusion of the Ordnance Engineers was a signal triumph for the perseverance of the Controller (Mr. E. V. Haigh).

Locally also, the re-organisation consequent upon the formation of the new department proved no easy task. Owing to the tardy co-operation of the supply controllers, any hard and fast organisation set up immediately upon the formation of the department ran the risk of having to be scrapped as soon as an advance was made: on the other hand, it was impossible to leave the reorganisation of the area staff until all arrangements had been made with all the supply controllers. Eventually an arrangement was evolved in August whereby the Superintending Engineer under the Area Organisation scheme was transferred to the Department of Engineering, and was to be the chief representative of the department in the area. The staff under his control was to be divided into sections, each section being detailed for the work of a particular supply department, and being in close touch with that department, though under the control of the Department of Engineering. Beneath these again were the assistant engineers who would be a free-lance staff, capable of being transferred from one section to another according to the pressure of work. This scheme was designed to obtain the central control of local production which experience had proved to be essential, while at the same time it would allow for expansion as the different supply departments were prevailed upon to allow their outside staffs to be incorporated. By simply adding new sections within the existing framework the organisation could be expanded till it fulfilled the original idea of its promoters, the inclusion of all outside staffs, not merely those of the Ordnance Group, under the control of the Area Engineer, who would be the local representative of the Department of Engineering and would work in co-operation with the local representatives of other common service departments like the Labour and the Munition Works Department at the common local headquarters, the Area Office.

When the Armistice was signed the organisation of the new department, both centrally and locally was well advanced. Not only was it on its way to obtaining the position designed for it within the Ordnance Group, but it was also proving its value to other departments outside the group, and thus preparing the way for an extension of its functions to the logical end. Experience of the working of the department had shown that the fears expressed that the output of individual supplies would be jeopardised were not well grounded, and that departmental success could be attained as well by co-operation as by isolation.

The formation of the Department of Engineering, even though incomplete, illustrates the triumph of a principle, the principle of co-ordination and balanced effort between the parts of the organism to ensure the well-being of the whole. That principle had been clearly grasped by those who in 1915 had conceived the whole gigantic organisation, it had been lost sight of in the pressure of 1916 and 1917, when "getting the stuff out" was the primary object of all; it was returned to in 1918, because experience had proved that failure in principle involved failure in results. The period between the formation of the Department of Engineering and the termination of hostilities was not long enough for the scheme to reach its full development or prove its ultimate value, but there can be little doubt as to the soundness of the principles on which it was based.

VOLUME IX

REVIEW OF MUNITIONS SUPPLY

PART I

MUNITIONS PROGRAMMES

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CHAPTER I.

THE PROGRAMME OF DEMAND.

I. Introductory: Different Classes of Programme.

The longer the war lasted the more apparent became the importance of forecasting with exactitude on the one hand the Army's needs, on the other the possibilities of their fulfilment, and of finding, by the balancing of these two, a complete comparison between the needs of the Army and the likelihood of their fulfilment.

The scale upon which provision was to be made depended primarily upon arrangements for increasing the strength of the forces, and upon requests which were received from the army in the field for supplies to satisfy immediate needs or for provision against future developments in the campaign. These factors, considered together and systematically formulated, became one kind of programme, namely, a programme of demand.

There was, however, a large difference between desire as expressed by a programme of demand, and the possibility of achievement, as formulated in a second class of programme, namely, the programme of supply. In this, account was taken of the normal length of time occupied by manufacture and of all the manifold circumstances which affect the progress of production. In its simplest form, the programme of supply was a statement of estimated deliveries from the workshop; at a more advanced stage it became a complex calculation based upon the various means for using to the best purpose all the nation's resources in labour, money, materials and transport facilities, as well as in manufacturing capacity.

Given a programme of demand, or the expression of desire and a programme of supply, or the anticipation of fulfilment, it is still necessary to find the final programme. This is the complete programme which is found by a systematic combination of the two earlier statements. It shows the best possible method of satisfying the needs of the Army from all the resources available. It provides for the army commander a reliable basis for estimating his resources in *matériel* at any future point of time; it enables the supply authority to organise production to the best purpose. It is only by the comparison of the complete programme with actual achievement that success or failure in equipping the troops can be assessed.

II. The Tactical Basis of Demand.

(*a*) The Fixed Establishment.

At the beginning of the war a fixed standard existed for the equipment of the forces as they then stood. The establishment in artillery of various calibres was defined. The scale of ammunition to be provided for each gun was determined. It was anticipated that

general engagements would be only occasional and that the ration of ammunition per gun could thus be made good in the interval between actions. The standard of equipment with other classes of warlike material was similarly defined. For instance, two machine guns were assigned to each battalion. The rate of consumption of small arms ammunition could only be determined by experience, and for a considerable period the figure was fixed more or less arbitrarily, provision against any under-estimate being made by building up a reserve.

(*b*) Changes in the Establishment.

The very first months of actual warfare brought about remarkable changes in the nature and scale of the establishment. In September, 1914, steps were taken to provide heavy artillery for use in the field, as well as the field guns and comparatively light artillery to which the equipment of the Expeditionary Force had formerly been restricted. Preparations were made in the same month for providing high explosive, as well as shrapnel, ammunition for field guns, although the exact proportions of these two classes of ammunition were not decided until a much later date. In November, 1914, the number of machine guns per battalion was doubled; by the following June it was quadrupled.

The most remarkable change took place in the scale of the gun ammunition ration. The rate of consumption speedily exceeded any former expectation. Owing to the continuous nature of the operations the expected intervals did not occur for replenishing the allowance originally made for each gun. The daily expenditure of rounds per gun became the new basis of calculation, and as early as September, 1914, the daily expenditure of 18-pdr. ammunition was double the current rate of issue. At the end of 1914 the Commander-in-Chief formulated a request for an enormous increase in the daily rations per gun, and although these figures were subsequently modified they exceeded the later maximum requirements in one instance only.[1]

(*c*) Growth of the New Armies.

The growth of the armies was even more remarkable than these rapid increases in the scale of their equipment. Upon mobilisation, the total forces of the Crown numbered scarcely 700,000, including Territorials, the Indian Army and the Reserves. During the first year of war over 2,000,000 men were added, and even after this the new armies continued to grow. The original British Expeditionary Force consisted of six divisions. By the end of August, 1914, the War Office was aiming at a total strength of 30 divisions. In the summer of 1915 demands from France alone were calculated upon an ultimate standard of 50 divisions to be reached by the following spring. The requirements formulated for the Ministry of Munitions by the War Office at the end of June, 1915, contemplated a strength of 70 divisions, and in the latter part of that year the Ministry took for its ideal the final equipment of 100 divisions, a standard which was accepted by Lord Kitchener as the limit of the nation's capacity. Although this figure was never

[1] For the details of these changes *see* Vol. I, Part I.

quite reached, even the less ambitious standard of 70 divisions involved the equipment of a force nearly twelve times as large as the army which had crossed to France in August, 1914.[1]

(*d*) EFFECT OF THE WAR OF POSITIONS.[2]

Concurrent with these vast developments in numbers and in the scale of equipment there came an absolute, and entirely unexpected, change in strategy. British military authorities had relied upon the rifle and bayonet alone as the short range weapon for an army which was expected to be perfectly mobile and was intended mainly for outpost duty. The Army was provided with no equipment at all for trench warfare. There were not even patterns for some of the more important weapons suitable to a war of positions. The British forces lacked any experience upon which to base their demands for these.

Trench warfare became an established condition upon the Western front in October, 1914. The actions of 1915 only served to emphasise the likelihood of its being prolonged, at least until the Allies could put forward their full strength in men and equipment. The need for attacking positions rather than armed forces increased the proportions of the demand for high explosive ammunition, although throughout the war the British Staff preferred on the whole to use shrapnel, rather than high explosive shell in their field guns for such purposes as wire cutting and the shelling of communications.[3]

The first demands for trench weapons proper, the mortar with its ammunition and the hand grenade, were the direct result of the battle of the Aisne, in October, 1914. Before the scale of equipment could be considered, it was necessary to invent and test these weapons. Twelve mortars had been issued with scanty supplies of ammunition by the end of the year. By June, 1915, it was estimated that 500 mortars should be put into the field as soon as possible, their number being limited only by the amount of ammunition available. Short supplies of bombs strictly limited the use of trench mortars in the battle of Loos (September, 1915), while emergency types of grenades only were then available in any quantities. Until October, 1915, the requirement for these stores was practically unlimited. All that could be made would be used.

Prolonged warfare in the trenches gave rise to all kinds of demands for strange and miscellaneous equipment. The periscope, at first provided by the individual officer as a kind of new toy, was ultimately demanded in large quantities, which by the end of the war exceeded 60,000.[4] Mechanical engines for propelling bombs in to the enemy's trenches had a brief day while the supply of the more efficient mortar was being organised. The use of armour was considered from time to time, but the design of body armour which should be sufficiently light as well as effective was still an unsolved problem when the war ended.

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[1] For the details of this development *see* Vol. I, Part I.

[2] *See* Vol. XI, Part I.

[3] *See* Vol. X, Part II, pp. 2-7, for an account of variations in the proportions of H.E. and shrapnel required.

[4] Vol. XI, Part III., p. 133.

The provision of a steel helmet was an imitation of a French practice begun in the spring of 1915. The first demand for 25,000, formulated in September, 1915, was speedily increased to a million and more. Thenceforward, allowance was made for equipping every man in the field with a helmet and providing also for wastage, and in 1917 provision was made for supplying the Home Commands also, as a protection against anti-aircraft barrage.

(e) Novel Forms of Warfare.

Within a year of the outbreak of war the enemy adopted two new methods of attack, using chemicals for the first time in April, 1915, and flame projectors against the British trenches at the end of July.

The most urgent demands arising from these novel methods were for a means of defence. At the very first, the requirement for defensive apparatus was limited only by the size of the army in the field, for every man had necessarily to be provided with his own equipment. There was, in addition, a large requirement to cover wastage. The nature of the defence developed very considerably with changes in the qualities of the chemicals. The simple respirator gave way to a flannel helmet fitted with mica or celluloid eyepieces, which was in turn replaced by the box respirator filled with solid absorbents. The cumbersome box respirators of 1916 were issued to certain *personnel* only, and the whole Army was equipped from August, 1916, onwards with a smaller type, more suited for general purposes. Demands for miscellaneous defensive apparatus arose with new developments in chemical warfare. Thus, the introduction of mustard gas by the Germans in 1917 led to demands for appliances to protect the whole body as well as the eyes, nose and mouth.[1]

Almost concurrent with the demands for defensive apparatus came the call for a means of retaliating. In the nature of things the army in the field was in a better position for defining the results which were desired than for fixing the nature and quantity of the equipment for producing them. The scheme for the first British cloud attack was formulated in June, 1915, and it was carried out with chlorine from cylinders at the battle of Loos in the following September. Arrangements were made simultaneously for the provision of a more powerful cloud gas ; but the policy of providing highly toxic substances in projectiles, which was advocated by the Commander-in-Chief from June, 1915, onwards, was not definitely accepted by the British Government until July, 1916. In the meantime, however, lachrymatory shell had been introduced into service. By August, 1916, chemical warfare was so far established that requirements for projectiles were formulated on a weekly basis. The quantity and nature of the chemical warfare supplies were thereafter subject to constant change with the advance of experience in the field, the imitation of new methods employed by the enemy and the growth of knowledge at home. After the first attack in April, 1915, the British programme

[1] Vol. XI, Part II, Chap. VI.

of defence was always ahead of the enemy's methods of offence. In the offence initiative remained with the enemy. The first large-scale retaliation for the cloud gas attacks of April was the cloud gas attack at Loos. The adoption of lethal artillery shell followed upon their use by the Germans at Verdun. The demand for mustard gas was a direct result of its use by the enemy in the summer of 1917.[1]

The nature of the enemy's *flammenwerfer* had been known before the German flame attack of July, 1915, and certain patterns had been developed. In August the Secretary of State authorised the manufacture of four-cylinder stationary batteries ; but the greater number of these were issued to Russia, and the only flame-projector used at all extensively was the large-gallery type, which was discharged with considerable effect at the opening of the battle of the Somme (July, 1916), and was used occasionally afterwards.[2]

(*f*) THE DEVELOPMENT OF MECHANICAL WARFARE.

Developments in the use of mechanical means for waging war were among the most remarkable features of the years 1916 to 1918. At the outbreak of war the equipment of the Expeditionary Force had included a fleet of motor vehicles, supplied by means of a subsidy scheme which had been introduced with the first development of motor transport. The increases in the armies and the enormous quantities of stores and ammunition supplied demanded by 1916 a corresponding advance in the size of this fleet. The number of vehicles increased steadily, and the allowance to replace casualties was exceptionally large, as the work of repair fell seriously into arrears. There was, however, no fixed establishment nor any definite figure for a reserve, and it was not until 1918 that a weekly requirement was formulated upon a basis which was purely provisional. Meantime, new classes of vehicles of very miscellaneous types had come into service. To the original demands for motor-lorries and motor-cycles, there was added at an early date a requirement for tractors to haul siege guns, and the equipment of the army in the field eventually included mobile X-ray lorries, telephone and telegraphic lorries, and special trailers for aeroplanes.[3]

It was not until comparatively late that requirements for railway materials arose on the Western front, as until 1916 the French railways sufficed. Preparations made in the latter part of 1915 for advances in 1916 gave rise only to provisional arrangements against a possible demand for track and rolling stock. The immense increases made during 1916 in supplies of munitions and other stores called for special provision in this respect, and systematic programmes of demands for railway material for the Western front were made in the autumn of that year, as a result of a survey of transport problems. Concurrent demands which arose for constructing railways in the Eastern theatre of war were increased in 1917 by a project for large railway extensions in Egypt. While the army in France remained more or less stationary

[1] Vol. XI, Part II, Chap. I, *see* below, p. 32.
[2] Vol. XI, Part I, pp. 96–98.
[3] Vol. XII, Part IV, Chap. I, III.

during that year, the chief railway requirement was for increases in rolling stock. The losses of the retreat in the spring of 1918 had to be replaced from the reserves, and the plans for subsequent advance involved large programmes for relaying track destroyed by the retiring enemy, and for bringing up supplies along the lengthened lines of communication.[1]

The railway and motor vehicles brought supplies within a short journey of the advanced troops. Across the fire-swept, bebogged area behind the front line all supplies had to be man-handled or carried on mules. The broken country dividing the two lines of entrenchment was a formidable obstacle to any advance. The need for cross-country traction to distribute stores along the front line led, towards the end of the war, to some demand for overhead ropeways and for a cross-country tractor capable of bringing stores closer to the front line and of keeping up with advancing troops.

The most remarkable of the mechanical contrivances introduced during the war was the tank, which appeared in action as a dramatic surprise in September, 1916, and at the battle of Cambrai (April, 1917), established its value as a weapon of war, particularly as a substitute for intense artillery preparation before an advance. Its invention was not so much due to a formal demand from the army in the field as to the faith of a few individuals in the effectiveness of a mechanical engine for overcoming the conditions of trench warfare. Its first acceptance by the Army in January, 1916, was followed by a period of vicissitude in which the demand fluctuated with changes and experiences in the field. The requirement ultimately rose from the one hundred fighting machines for which the War Office asked in February, 1916, to 3,600, the number of new machines needed for the 1919 campaign. In the end the utility of tanks for open as well as siege warfare became apparent, so that the changes of 1918 did not decrease the number required.[2]

(g) War in the Air.

An outstanding feature of the 1917 programme of demand was an enormous increase in the requirements for aircraft. When war broke out, both the Navy and the Army relied upon aircraft for certain reconnaissance duties. The one service was equipped with seven airships and about 70 aeroplanes, the other with rather less than 180 aeroplanes. The use of aircraft for the protection of the Grand Fleet and for anti-Zeppelin work and home defence generally was developed by the Navy during the first two years of warfare, while the reconnaissance work of the land service machines and their duties of co-operation with the artillery increased with great rapidity. The expansion of aerial warfare was, indeed, chiefly restricted during this period by limitations in the supply of machines.

In 1917, advances made by Germany in producing fast types of machines threatened the predominance of British aircraft on land. The unrestricted submarine campaign gave added importance to the use of aircraft over the sea. The development of bombing operations,

[1] Vol. XII, Part V.

[2] Vol. XII, Part III.

which had first been organised upon the Western front in 1916, also gave rise to very large increases in the demands for aircraft. A new and important source of requirements came into being towards the end of 1917, when the Army accepted the principle of long-distance bombing, requiring 66 new squadrons for this purpose alone. The programme of demand was thus heavily increased by the requirements for the Independent Air Force, which was finally established in June, 1918.[1]

A large and varied programme for armament and equipment arose out of the developments in the demand for aircraft. Some idea of the proportions of these new requirements may be gained from the programme of August, 1917, for machine guns to arm aircraft. It was then calculated that machine guns would be needed by September, 1918, at the rate of 4,620 per month to meet the needs of aircraft alone, and this figure represented more than 50 per cent. of the machine gun demand for all purposes.[2] The programme for bombs developed simultaneously, and the tonnage of the bombs to be provided grew in even greater proportion than their numbers.[3] In addition to armament, each machine needed a large and miscellaneous equipment, which included various types of delicate instruments and accessories for registering height and guiding direction, as well as for the comfort of the crew. The development of aerial warfare brought with it also new demands for signalling apparatus, both for sight and sound. The need for anti-aircraft defence, similarly, gave rise to requirements for height and range finders, and for instruments to locate sound, as well as for special types of guns and ammunition.[4]

(*h*) ARTILLERY DEVELOPMENTS AND THE EFFECTS OF OPEN WARFARE.

Between 1914 and 1918 the basis of the munitions demand was thus enormously widened by the introduction or expansion of novel forms of warfare. There was no concurrent decrease in the demand for munitions of the older types; on the contrary, some of the largest classes were expended at rates far exceeding any former anticipation.

While the development in rifle requirements was calculated to reach its climax when the full strength of the new armies should have been put into the field in June, 1916, there was on the whole a distinct tendency towards a steady increase in the demand for small arms ammunition even after that date, and increases in the numbers of rifles and machine guns, together with the introduction of barrage fire from machine guns, gave rise to increased demands in the latter part of 1917. Again, enormous losses suffered during the German offensive and heavy expenditure during the severe fighting of April, 1918, seriously depleted stocks, and the demand reached its climax of 550 million rounds during that month.[5]

The large increase in the consumption and use of munitions was, however, most remarkable in the case of gun ammunition. During

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[1] For the development of the aerial policy *see* Vol. XII, Part I, Chap. I.
[2] D.M.R.S., 135 M.
[3] Vol. XII, Part II, pp. 15–18.
[4] Vol. X, Part VI.
[5] Vol. XI, Part VI, Chap. IV.

1915 all the ammunition available was accumulated for the autumn offensive, and in a single week of September 600,000 rounds were expended during the battle of Loos. This rate of consumption was not, however, maintained. During the winter months it fell to about 100,000 rounds a week, while preparations were again being made for the campaign of the next summer. In the first week of the battle of the Somme nearly 2,400,000 rounds were expended; and although this rate, largely due to the intense bombardment preceding the attack, fell during the succeeding months, it did not reach a point far short of 1,000,000 rounds a week until the month of November. Even the comparatively quiet period of the succeeding winter was characterised by a consumption of shell which was often in excess of that at Loos. The battle of the Somme, however, had proved that the existing rations of ammunition for all types of gun were inadequate. Accordingly, in October, 1916, the demand was raised for nearly all natures, the most striking increase being for the field guns. The ration of the 18-pdr. in 1917 was to be calculated at 50 rounds daily, instead of 25.

The demands of October, 1916, were formulated in the hope that the Army would be equipped with its full establishment of guns by June, 1917. The ammunition programme was thus intended to provide a full daily ration upon a very greatly increased scale for a full establishment of guns. The supply of shell had already ceased to limit the rate of fire, and the effect upon the wear of the guns was becoming extremely grave, even though the wastage could be lessened by the use of reduced charges. In February, 1917, the programme for gun ammunition ceased to be entirely controlled by demands received from the army in the field. Thenceforward it was strictly regulated by the need for balancing the repair and output of guns with the production of ammunition, and by the increasing stringency of the economic situation.[1]

In spite of these difficulties the gun ammunition programme for 1917 still exceeded that for the previous year, and the actual expenditure far exceeded that of any previous campaign. The weekly expenditure during the third battle of Ypres was beyond 3,200,000 rounds, and was only subsequently exceeded during the final Allied offensive of September–October, 1918, when in a single week nearly 3,500,000 rounds were fired on the Western front. The proportionate use of heavy shell was steadily increasing. During the Somme battles of 1916, 25,394 tons of gun ammunition were fired weekly on the British front. During the campaigns of 1917 an average of 43,300 tons was fired weekly. And all the while there was a continuous competition with the enemy in length of range, giving rise to modifications in the guns demanded and to changes in the pattern of the shell.

The prolonged artillery bombardments which preceded the previous attempts to break through the enemy's lines ceased with the development of open warfare in 1918; but the rate of expenditure of ammunition did not seriously decrease. The result of the open fighting was to leave the tonnage requirements for gun ammunition unaltered. Although the demand for heavy howitzer shell filled with high explosive diminished,

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[1] *See* below p. 41.

there was an increasing need for light shell and for smoke and chemical ammunition. British counter-battery work continued to have a very remarkable effect. During the British offensive in September, 1918, the expenditure reached the unprecedented figure of 86,000 tons per week. It was only on account of restrictions in the country's resources that the actual programme for the 1919 campaigns was reduced in October, 1918, to allow for an expenditure of 50,000 tons of gun ammunition per week, instead of the 57,000 tons previously anticipated.[1] The main features in the programme for 1919 were preparations made for producing an 18-pdr. gun of new design, for supplying increased proportions of chemical shell and for providing large numbers of aeroplanes and tanks in addition to special arrangements for the productions of all kinds of railway material.[2]

III. Other Factors Governing the Demand.

The demands for the Western front, took precedence by reason of sheer bulk. Those for other theatres of war were not only of great importance, but were often of a very special character. As provision had to be made for differences in climate and in the conditions of war, these requirements needed separate consideration and were by no means always to be met by merely increasing the quantities to be provided for the armies in France. There were, moreover, several other sources whence urgent demands were apt to arise. Whilst naval demands for munitions were excluded from the Ministry's munitions programme, except so far as concerned the allocation of certain resources,[3] one or two stores, such as high explosives, were obtained for both Services; but the interchange of warlike material, as well as of industrial capacity, between the Navy and the Army occasionally had an important effect upon the programme of land service supply.

From time to time, also, the essential needs of the community made imperative demands upon supplies which were also needed by the armies. The extent to which it was practicable to divert raw materials and industrial capacity from commercial to military use was one of the main problems of the supply programme.[4] The whole programme of munitions supply became secondary to the arrangements for food supply towards the end of the war.

The largest supplementary demands came from the Allies. It was from the first recognised that their pressing needs constituted a certain claim upon British resources; but the demand was usually measured rather by the surpluses which could be converted to their use than by any more definite standard. It was not until 1918 that the spasmodic efforts of the Allies towards unity of action secured a common munitions programme.[5] The inter-allied programme for 1919 was rather a supply programme than a statement of a common military demand. Its very existence was due to the importance which then attached to considerations of supply, and it marked the climax of a development in the relative importance of the supply programme, which is considered in the chapter which follows.

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[1] Vol. X, Part II, Chap. I. [2] HIST REC./R/1000/115.
[3] *See* below, p. 39. [4] *See* below, pp. 12–15. [5] Vol. II, Part VIII.

CHAPTER II.

IMPORTANCE OF THE SUPPLY PROGRAMME.

I. Introductory.

The programme of supply advanced steadily and rapidly, side by side with the programme of demand, until 1916. Its progress during this period was almost unrestricted save by the limits which were imposed by the time needed for organising productive capacity. Just as the organisation of the nation's resources was fully completed, and as preparations were being made to bring the whole of the country's industrial powers into play for the campaign of 1917, this advance was checked by economic forces. The check was partly the outcome of the enemy's unrestricted submarine campaign and partly the logical effect of a war of attrition.

The programme of supply attained a new importance under these new conditions. It began to rank as equal with the programme of demand. Limitations of output controlled the final decisions of 1917. The programme of supply thus became the governing factor in the final practicable programme. Ultimately, in 1918, the general stringency was so widespread that the individual programmes of the combatants were swallowed up in a general programme, which was based upon the Allies' resources considered as a single whole.

II. Factors Governing the Programme of Supply.

In time of war the programme of supply depends upon three principal factors. These are, firstly, the normal time which must be occupied by the various stages of production, secondly, the capacity of the munitions works for meeting the demand either from their existing capacity or by the aid of expansions, and finally, the measure of the whole resources of the country when applied to the production of warlike stores.

(*a*) The normal Time-lag in Production.

The time actually occupied in producing various classes of munitions differs enormously. Guns, machine guns and rifles, which are complex weapons and need a very large proportion of adjustment and skilled hand-work, can only be produced within minimum periods, which are rarely much less than twelve months, though they vary with the nature of the article, the difficulty of the specification and the circumstances of the manufacturer. Repetition work upon such munitions as small arms ammunitions or shell occupies a less period of time; but even the production of the complete shell from the forging was found during the war to take three months or more. The simplest forms of trench warfare projectiles could be made within a week or so. It was scarcely ever possible to buy supplies ready-made in the open market.

Production by assembling together numerous components manufactured in different factories entailed the transportation of large quantities of material, which occupied periods of time dependent upon the organisation of storage and the general arrangements for transport facilities within the factories themselves. Allowance had also to be made for two further operations, namely, inspection and design. The imperative need for ensuring absolute safety and reliability in every munition of war involved much detailed work in testing materials, watching the course of manufacture and finally examining and proving the finished article. For example, these processes in the case of gun ammunition occupied about a fortnight; under the less urgent conditions of peace-time, two months had been assigned to them.[1] The serious delays which arose from the development of new designs and the modifications of existing patterns were more difficult to gauge than the time to be occupied by inspection. These depended upon entirely unknown quantities, such as the length of time to be occupied by research and experiment, the success or failure of experimental manufacture and the speed with which manufacturers in bulk could acquire new plant or convert their old and train operatives in new and unaccustomed operations. The influence of this factor over the programme of supply can scarcely be exaggerated.[2] Experience provided some basis for judging the minimum of delay involved in changing over to the production of one pattern instead of another. It was possible to contrive that continuity of supply should not be broken by modifications in design.[3] The normal period to be occupied in the procedure for adopting new patterns was gradually reduced to a minimum; but to the end, the time taken by invention, research and experiment remained extremely variable, since it depended very largely upon the workings of the human mind.

(*b*) The Capacity of the Established Munitions Works.

Until March, 1915, the policy followed in regard to munitions supply was one of entire reliance upon expert makers, namely, the Ordnance Factories and the great armament firms. The only expansions which took place in the sources of supply during this period were the stimulation of sub-contracting amongst the general engineering trade of the country and the placing of extensive orders in foreign countries.[4] It followed that any forecast of future supply rested upon promises of deliveries received from the Ordnance Factories and from contractors. Basing a conservative estimate of achievement upon long experience, the Ordnance Factories were usually able to make forecasts with some exactitude, but the estimates of the armament firms were inclined to be too sanguine in respect of early delivery.[5] Under the pressure of war conditions, hampered by unusual difficulties in obtaining labour and materials, struggling to meet the continually increasing demands which were made upon them, and thrown out

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[1] Vol. IX, Part II, p. 37.
[2] For a more detailed account, *see* Vol. IX, Part II, Chap. VII.
[3] *See* below, p. 47.
[4] *See* Vol. I, Part III, pp. 1–5.
[5] Vol. I, Part I.

of balance by the unforeseen difficulties which their new sub-contractors experienced, these firms failed to make good many of their promises as to delivery. Thus the whole basis of the forecast for home supplies was overthrown. The armament firms were, moreover, being constantly asked to make extensions, and to judge of the moment at which output would begin from these was no easy matter. Efforts to estimate when the output from such extensions would begin met with varying success. Unexpected delays arose out of the general competition between the firms for certain classes of equipment such as machine tools.[1] The supply of skilled engineers to work the extensions when complete became, by the end of 1914, exceedingly problematical.[2]

Contract officers had some knowledge as to how much reliance could be placed upon the estimated rates of delivery promised by the British armament firms. They had no corresponding experience in regard to foreign manufacturers. From October, 1914, onwards, large purchases were made in Allied and neutral countries, and particularly in the United States of America. The risk of failure through the speculations of middlemen dealing in options and through all the uncertainties of an untried market was minimised in the United States by the appointment of a Commercial Agent,[3] who at first also recorded the progress of delivery.[4] Deliveries from American manufacturers were, however, frequently delayed by the unforeseen difficulties which hampered all makers inexperienced in the production of the high-class munitions demanded by Great Britain.[5] The uncertainties of shipment under war conditions added another unknown factor to those which already controlled the programme of supply from abroad.

Under the circumstances outlined above any attempts which were made to forecast future deliveries were destined to almost inevitable failure.

(c) The Measure of the Country's Resources.

The enlargements already undertaken by the armament firms were enormously increased as a result of conferences on shell supply in December, 1914. The provision of additional skilled engineers was the chief factor which then prevented the speedy expansion of the munitions industry.[6] Projects for diverting labour from commercial to armament work led to a reflex policy of utilising commercial capacity for munitions production, and so to the mobilisation of general industry for the purposes of the war. This movement began with the organisation of co-operative groups early in 1915. It developed in May, 1915, into schemes for shell manufacture in new national factories. It culminated in the following June in the establishment of the Ministry of Munitions "to organise the resources of the country for the supply of munitions."[7] Thenceforward the programme of supply was restricted only by the extent of the

[1] Vol. I, Part III, p. 82.
[2] Vol. I, Part II, p. 2.
[3] Vol. II, Part III, Chap. I.
[4] *Ibid.* Chap. II.
[5] *Ibid.* Chap. III.
[6] Vol. I, Part II.
[7] 1/Gen. No./1534.

country's resources and by the power to organise them for producing war-like material. It was the policy of Mr. Lloyd George, as Minister, only to limit his arrangements for supply by the maximum of possible achievement.[1]

The enormously increased demands of 1915 were met by the establishment of new factories and the conversion of industrial undertakings to munition production. The creation and organisation of the new capacity which was chiefly intended for producing gun ammunition occupied the period between 1915 and 1916. Its output was first used in quantity towards the supply programme for 1916; its full productive power became available for the 1917 programme.[2] During this period the provision of plant and equipment was a factor which threatened to limit the speedy establishment of new factories for all kinds of munitions. Delays in obtaining machine tools restricted expansion during the spring of 1915.[3] Provision was ultimately made for equipping the new factories by a central organisation of the machine tool trade, and mainly by encouraging sub-contracting amongst the general engineering industry.[4] Local enterprise meantime organised the transfer to the National Shell Factories of machines occupied on less essential work.[5] Small tools were required by the new factories in large numbers, and this demand was continuous, owing to the wear and tear to which these tools are subject. Many of the established small tool makers extended their works. When these proved insufficient other industries were absorbed into the small tool trade, and a National Tool Factory was established in 1916.[6] The demand for gauges had also outgrown the normal capacity for supply even before the Ministry began to organise the expansion of the munitions industry. Sub-division of munition manufacture among numerous firms added to the number of gauges needed for each store. Great delays attended the efforts of inexperienced firms to make their own gauges. The Ministry's gauge orders were spread over large numbers of firms, accustomed to all classes of precision work, and experienced makers were induced to extend their factories as national undertakings. The new munition works were thus finally equipped with their full complement of gauges, and provision was made for replacing worn gauges. It was only occasionally after 1915 that the supply of gauges lagged behind demand. This was, as a rule, the result of changes in design.[7] In the summer of 1916 the provision of a single small article of industrial equipment, the ball-bearing, threatened to delay not only the equipment of factories, but the programmes for supplying military stores, such as motor vehicles, aircraft and tanks.[8] A tightening of control over the whole of the machine tool trade in 1918 was intended to prevent the reduction of imported tools from limiting supply.[9] The construction and equipment of new factories which were needed to provide against new demands, such as the extended aircraft programme in 1917, were seriously hampered by the same shortages

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[1] Vol. II, Part I, Chap. II.
[2] Vol. VIII, Part I, Chap. II.
[3] Vol. I, Part III, p. 82.
[4] Vol. VIII, Part III.
[5] Vol. II, Part II, p. 2.
[6] Vol. VIII, Part III, pp. 51–52.
[7] Vol. VIII, Part III, Chap. I.
[8] Vol. VIII, Part III, Chap. III.
[9] *Ibid.* p. 49.

which then directly limited the programme of supply. By 1917 the country had practically reached the limits of its capacity for establishing new factories. Thenceforward, enlarged output was chiefly obtained from the close control of industry in the interests of increased efficiency.[1]

The grave effects of the shortage of skilled engineers upon the programme for munition supply in 1915 was an indication only of the importance which the provision of labour was to have throughout the war. Many methods were tried for preventing the limitation of munitions output by lack of operatives. It was considered necessary from time to time to secure the modification of trade union restrictions, to stimulate the absorption of labour into essential industries, to introduce the employment of women and juveniles upon work which they had never before undertaken, and to regulate the flow of labour into the three most important channels open to it, namely, enlistment in the Crown forces, employment in munitions manufacture or employment in other essential industries.[2] These measures succeeded in manning the great new factories which were established during 1915 and 1916. Nevertheless, there was by the end of war a reduction in the labour strength of the country which amounted to a numerical loss of 871,000 persons, and was in fact still greater owing to the relative inexperience and inefficiency of the new recruits to industry.[3] In the last two years of the war, also, the shortage of certain classes of workers, such as builders, restricted projects for expanding munitions capacity. The "clean-cut" of certain classes of workers for recruiting the forces after the German advance in the spring of 1918, gravely affected not only the direct munitions industries but also the supply of coal upon which it depended.

At first little difficulty was anticipated in obtaining raw materials to feed the new factories. Before the summer of 1915 the only limitation upon output which was seriously threatening through lack of materials had arisen in the case of explosives.[4] It was not until December, 1915, when a severe shortage of aluminium became apparent, that the lack of any particular metal threatened to restrict output. Thenceforward, however, with the general development of munition production, the supply of metal after metal began to fall short of the demand.[5] It was only by using various means for stimulating output and encouraging economy and by gradually introducing different forms of control over essential materials that the Ministry ensured adequate supplies.

The provision of shell steel was a very important factor in the programme of gun ammunition supply which was formulated by the Ministry in 1915; but the output of the British steel industry, as organised in 1915, together with large imports from America, more than sufficed for the requirements of Great Britain, and allowed considerable surpluses for her Allies. The gun ammunition programmes

[1] For the gradual development of the Ministry's organisation to this end, *see* Vol. VIII, Part IV.

[2] The methods used for regulating the supply of labour are described in Volumes IV, V, VI.

[3] Vol. VI, Part IV, p. 19.

[4] Vol. X, Part IV, Chap. III, IV, VII.

[5] *See* Vol. VII, Part III.

remained unaffected by the position in regard to steel until the spring of 1917. The submarine campaign had then already begun to limit imports both of steel and of ore, and had increased enormously the demands for steel-plates for ship building. The shell steel programme was only maintained during the last quarter of 1916 at the expense of other important steel supplies, such as constructional steel. Military demands for steel for other purposes than shell were also increasing. Tanks, railways and mechanical transport all required increasingly large quantities. From the spring of 1917 onwards the steel position dominated the whole programme of supply.[1]

Shipping facilities also sufficed until the end of 1916. The Ministry of Munitions was an importer on a huge scale and took a growing proportion of the available shipping space, particularly for shipments of iron ore; while the large advances made in munitions productions made growing demands upon the means of transporting supplies to the troops. The first effects of lack of tonnage upon the munitions programme were felt at the end of 1916.[2] Thenceforward the tonnage budget became the ultimate factor which controlled the programme of supply, since it was upon the possibilities of importing iron ore and steel that the programme was largely based.[3]

During the first expansion of productive capacity it was considered that the taxpayer's first interest lay in adequate supply, and, with little restriction, the whole of the national wealth was available for the purposes of the war from December, 1914, onwards.[4] Financial considerations were thus secondary to the urgency of securing early deliveries and erecting new factories. In 1916, when the productive capacity of the country had been brought up to the level of the new armies' demands, the financial aspects of supply began to receive more consideration; but the development of financial control over programme-making was slow and was set about with many difficulties.[5] It was some time before the gradual exhaustion of foreign credits and the growth in the adverse balance of trade seriously affected the general programme for munitions supply. The earliest and most severe effects of the growing financial stringency were necessarily most apparent in respect to overseas purchases. Serious exchange difficulties, which threatened to limit purchases of munitions in Canada during the autumn of 1915, were at first overcome by means of advances from the Canadian Government and by raising local loans in Canada. By the summer of 1917, these methods of financing munition manufacture in the Dominion had been practically exhausted, while the restricted credits available were urgently needed for purchasing food supplies. Accordingly, from July, 1917, onwards, orders for the future supply of munitions from this source were reduced by nearly 50 per cent.[6] Until the entry of the United States of America into the war, difficulties in regard to rates of exchange were also increased by the financing of

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[1] Vol. VII, Part II, Chap. I.

[2] Vol. VII, Part V, Chap. I.

[3] See below p. 35.

[4] The Treasury then dispensed with covering sanction for expenditure "vitally necessary to the public interest" (Vol. III, Part I, p. 2).

[5] See below, p. 40.

[6] Vol. II, Part IV, Chap. VI.

American purchases for the Allies out of British credits.[1] Towards the end of 1916 the programme for supplies from the United States had to be definitely restricted for lack of dollars,[2] and thenceforward the financial position seriously restricted purchases in the United States, and occasionally gave rise to actual reductions in the programme.[3]

III. The Development of Programme Making.

The development of the actual making of programmes was a direct outcome of the gradual pressure which these various limiting factors applied to the business of supply. War Office supply programmes were statements of deliveries promised by contractors with some allowance for over-sanguine estimates. The supply programmes which were formulated by the Ministry during 1915 and 1916, whilst the expansion of productive capacity was the main problem in view, still continued to take the form of a series of forecasts of production, although they were calculated upon a more elaborate basis than before.[4] In some exceptional cases, they included tables for balancing the output of one store against another, to which it was closely allied. Thus the programmes for guns and gun carriages were balanced one with another from the autumn of 1915 onwards. In some important instances, estimates went back beyond the final output of the completed store to all the stages in its production. Thus, from the spring of 1916 onwards the programme for gun ammunition was based upon detailed calculations as to the output of components and empty shell and the time occupied in filling and completion, and the gun ammunition programme for 1917, which was prepared at the end of 1916, included separate calculations for the supply of materials, shell bodies, components, explosives and filling. This programme was carefully considered by the Minister's Advisory Committee in consultation with heads of departments, and account was taken of the constructional work and additional labour required.[5] The Committee also recommended that a co-ordinated programme should in future be obtained by centralising responsibility for the statistics relating to all stores.[6]

During this period (1915–1916) each supply department of the Ministry was solely bent upon producing the maximum possible output of its particular store. The system had succeeded so far because military requirements had risen in a steady *crescendo*, and because the men, materials and money had been forthcoming to feed the new factories. By the end of 1916, growing limitations in all these resources made it clear that some more general form of supply programme was necessary to enable the Ministry to balance duly its numerous activities. It was plain that to follow farther the policy of the maximum possible

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[1] Vol. II, Part VIII, Chap. II.

[2] C.R. 4508.

[3] As for instance, in January, 1918, when the restriction in American credits for steel definitely prevented arrangements for supplementary production. (D.M.R.S. 555.)

[4] For the development of these individual programmes, *see* Chap. IV, below.

[5] A.C. 2. The Advisory Committee had been constituted in October, 1916, as a standing departmental committee, to which the Minister might refer specific matters. (*See* Vol. II, Part I, p. 165.)

[6] *See* below, p. 23.

output of every store would be to court disaster. The whole business of supply was coming to depend upon good judgment in the allocation of machinery, materials, labour and money. It was, accordingly, very necessary to keep systematic record of the limiting factors, for either the whole army of supply must march at the pace of the slowest man, or else special measures must be taken to hasten the laggards. The Central Statistical Conference, which was established in January, 1917,[1] had the systematic keeping of such records as its final object. The collection and co-ordination of reliable estimates as to the supply of materials, and as to the rate of production and inspection, with due allowance for time lag at each stage, were the first steps towards a comprehensive programme to cover the whole field of munition supply.[2] In February, 1917, the Minister began to have a decisive voice in correlating the demands for guns and ammunition, since the balancing of their output depended upon many factors outside the purview of the War Office.[3]

Meantime, as the programme for all classes of munitions became increasingly dependent upon a single determining factor, viz., the amount of shipping available, and as the supply of steel, which required the bulk of the shipping accommodation, thus became the dominating factor in nearly every supply programme, the next step towards a comprehensive programme was the translation of all requirements into terms of steel and the revision of the manufacturing programme by the steel budgets,[4] and, in consequence, by the tonnage allocation at the end of 1917. In August, 1917, the Advisory Committee was instructed to survey the munitions programme for 1918 as a single whole, for it was considered indispensable to the highest economy of all resources that general principles and main features should be settled before the individual items in the programme were considered.[5] Statements were prepared by the Director of Munitions Requirements and Statistics based upon War Office requirements, stocks in hand, rates of issue, wastage, repair, and available capacity. With the establishment of the Munitions Council in the autumn of 1917, a special Programme Committee, assisted by ten sub-committees, and under the chairmanship of the Minister, was appointed to deal with the general programme. As a result, a series of manufacturing programmes were prepared for 1918, covering all classes of stores and making due allowance for supplies of materials, labour, tonnage and cost.[6] The main basis of this programme was the amount of tonnage available, and this was also the foundation of the general programme for 1919, which began to be discussed in July, 1918.[7]

The preparation of a complete supply programme duly balanced in every particular was thus an accomplished fact, and its relation to the original programme of demand was established on a sound basis. The final programme was at length reached when the Ministry had laid its estimates of output before the War Office for modification or confirmation in the light of military conditions.

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[1] *See* below, p. 23.
[2] A.C. 34.
[3] *See* below, pp. 29, 41.
[4] *See* below, p. 35.
[5] Mr. Churchill, 9 August, 1917 (HIST. REC./R/1000/115).
[6] A.C. 128.
[7] HIST. REC./R/1000/115.

IV. The Inter-Allied Munitions Programme.

This final programme, however, still treated the needs of the Allies upon a distinct basis, and continued to do so until, with the establishment of the Inter-Allied Munitions Council in June, 1918, the making of programmes was undertaken upon an even wider scale. There had previously been no common munitions policy among the Allies. Their requirements had been formulated spasmodically with a view to obtaining warlike material from each other or to securing the benefit of British credits and the advantages of unity of purchase in neutral states. In Great Britain it had been a common practice to allocate surplus production for the use of the Allies. This method was entirely altered in the summer of 1918. A series of programmes was then prepared for 1919 for all four Allies—Great Britain, France, the United States and Italy—and, as far as possible, the surplus capacity of one country was used for the assistance of the rest of the alliance. Thus Great Britain and France arranged to help the United States with her gun and gun ammunition programmes. Great Britain agreed to continue to supply France and Italy with machine guns, to provide armament for the inter-allied tank programme, to continue to supply France and Italy with certain raw materials and so forth; and the United States agreed to continue to supply all the European Allies with raw materials.[1]

These programmes had a common basis in the complete tonnage programme which was formulated for all the Allies, and in arrangements made for the joint consideration of the financing of supply.[2] In fact, the Allied programme reflected the importance which supply conditions had attained in the formulation of the final programme.

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[1] Hist. Rec./H/1000/7. [2] *See* Vol. II, Part VIII.

CHAPTER III.

PROCEDURE IN REGARD TO REQUIREMENTS.

I. War Office Methods.

In time of war the requirements of the Army—the programme of demand—were based upon three definite factors, the size of the Army as determined by Parliament, the scale of equipment as prescribed in Army Regulations, and the rate of consumption. The Master-General of the Ordnance, through his subordinate officers, decided the nature and quantities of the stores to be provided, and the Chief Superintendent of the Ordnance Factories or the Contracts Department made the necessary arrangements for supply. Requisitions upon the Contracts Department took the form of "demands" for specific quantities. Apart from his presence at a yearly conference upon the allocation of orders between the Ordnance Factories and the trade, the Director of Army Contracts had practically no means of knowing the total demands or the probable future demands which might be made upon him,[1] nor of judging the general position as to supply. "Extracts" upon the Ordnance Factories passed to the Chief Superintendent, and the Contracts Department was unacquainted with the position at Woolwich, whilst records of deliveries were kept by stores or inspection officers, who only referred to the Contracts Department in exceptional cases. Thus, neither the Chief Superintendent of Ordnance Factories nor the Contracts Department was able to review as a whole, the supply position, which was only known in its entirety to the Master-General of the Ordnance.

With the outbreak of war the problem of formulating requirements became one of great complexity.[2] The procedure with regard to supply remained practically unchanged, but the transfer of the Armaments Contracts Branch to the Director of Artillery's department, at the beginning of 1915, brought the military and contracts officers into closer touch with each other, and placed the Master-General of the Ordnance in a better position for balancing the possibilities of supply against the standard of requirement.

II. Requirements as received by the Ministry.

When the Ministry of Munitions was established in June, 1915, its duties were said to begin when the requirements of the War Office, as regarded the kind, quantity and quality of the munitions to be supplied, had been made known to it.[3] The Ministry received this information in one of two forms, viz., day by day, or "spot" demands, and programmes. Spot demands were requisitions for a definite total number of stores, which, as the art of programme making

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[1] Hist. Rec./H/500/10 ; Hist. Rec./R/500/64.
[2] *See* above, p. 2. [3] Hist. Rec./R/265/2.

developed, were generally limited to small quantities. A programme, on the other hand, was a demand for the continuous supply of a given quantity per week or month, which had to be translated into terms of output by the Ministry.

Any statements of requirements received from the front or statements of stores foreseen by the War Office to be likely to be ordered in the immediate future were communicated to the Ministry of Munitions at once;[1] but during the first months of its existence the new Department experienced great difficulty in obtaining forecasts of requirements for any time ahead. On the one hand, the Army Council was anxious to restrict its demands as much as possible; on the other, the Ministry endeavoured to budget on a large scale and far ahead, in order to allow for the time-lag in developing productive capacity. There were great practical difficulties in the preparation of these early programmes, and in many cases the military officers concerned were not convinced of the necessity from the manufacturing point of view.[2] This difficulty was only overcome gradually.

The Ministry also received miscellaneous requisitions from the Admiralty, the India Office, the Board of Agriculture, the Air Board or Air Ministry, and from Allied Governments, generally in the form of spot demands. The requirements of the Air Ministry were received in the form of distinct demands, but the Director-General of Aircraft Production was a member of the Air Council, and by the end of 1917 the aircraft programme was included in the general munitions programme. During the first year of the Ministry's existence there was little uniformity in the treatment of Allies' requirements, but in September, 1916, it was arranged that all demands from Allied Governments must pass through the Commission Internationale de Ravitaillement to obtain the necessary financial sanction.[3]

III. Treatment of Requirements within the Ministry.

The task of receiving requirements and preparing manufacturing programmes, with all the variety of statistical and co-ordinating work which this entailed, fell to the lot of a branch of the Secretariat known as D.M.R.S. or the Department of Munitions Requirements and Statistics.

For a few weeks demands for munitions were addressed either to the Minister, the Contracts Department or a supply department, and there was no means of ascertaining the total obligations of the Ministry. It was obvious that some central branch must be established to act as a channel of communication between the War Office or other requisitioning authorities and the departments of the Ministry concerned. Accordingly, in July 1915, a Director of Requirements and Statistics (Mr. W. T. Layton) was appointed, and the functions of his department were defined as "to receive all demands for munitions put forward by the War Office, and to act as a distributing channel to the various Departments of the Ministry concerned."[4]

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[1] 1/Gen. No./1557.
[2] Memorandum by Mrs. F. Wood (HIST. REC./H/1000/7); HIST. REC./R/265/2.
[3] D.M.R.S. 407. A. [4] M.W. 22559.

The usual procedure was for D.M.R.S., on receipt of a War Office programme or demand, to obtain the necessary drawings and specifications from the inspection authority and to translate the demand into a manufacturing programme or definite order, which was passed to the supply departments concerned. The supply departments then prepared estimates of production, which were submitted to D.M.R.S. for co-ordination with other estimates and passed to the War Office for approval. The success of this procedure depended upon close co-operation. The preparation of complex and inter-related programmes with the minimum amount of delay, and the constant need for re-adjustment, was only possible as the result of personal discussion and the regular interchange of information. Officers were appointed in the Requirements Branch with responsibility for certain classes of stores, roughly corresponding to the different supply departments, and close co-operation with military authorities and supply officers was an essential duty of the department.[1]

A weekly report summarising the work of the different branches of the Ministry was prepared in the department and circulated to officers of both the Ministry and the War Office, together with lists of the requirements received, contracts placed and promised deliveries. The Director himself worked in close touch with the Minister and with heads of departments. He acted as secretary to the Minister's fortnightly meetings of heads of departments and eventually became Secretary for Requirements and Statistics. Shortly after the establishment of the Munitions Council in 1917, he became a member of the Council of which his department eventually became a group. He or his representative served on several Ministry committees,[2] and he was frequently called upon to represent the Ministry on missions, at inter-allied conferences and on inter-departmental committees.[3]

Although, from October, 1915, onwards, all formal correspondence with the War Office concerning the quality and quantities of stores, deliveries, etc., was conducted through D.M.R.S., and no alterations could be made except through this official channel, supply and military officers were still free to discuss questions of progress or manufacture in an informal way, and provision was made for urgent demands to pass direct to the supply departments, provided that D.M.R.S. was properly notified and the usual conditions were subsequently satisfied.[4] It was, however, some time before the procedure outlined in July and October, 1915, was universally adopted.[5]

Developments in the scope of the department's work were naturally accompanied by rapid growth in staff and organisation. The two branches of Requirements and Statistics into which it had been divided from the first were subdivided into sections dealing with different classes of supplies, until in July, 1917, the department consisted of five

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[1] HIST. REC./R/263.12/6

[2] *e.g.*, Steel Allocation, Coal Supply, Priority in Shipments Committees, Allocation of Urgent Supplies Board.

[3] *e.g.*, Milner Mission to Russia, Balfour Mission to U.S.A., American Board, Information Sub-Committee of War Priorities Committee.

[4] Departmental Office Notice, 18 October, 1915 (HIST. REC./R/263.12/1).

[5] D.M.R.S. 407 ; 407 A.

main branches dealing with War Office requirements and general correspondence (British Branch), requisitions for the Allies, inter-departmental requirements for metals, materials, and explosives, central statistics, and reports and records.[1]

IV. The Place of Statistics in Programme Making.

The methods of keeping statistical records were of extreme importance in the formulation of programmes. The detailed figures upon which the programme of demand was based fell outside the scope of the Ministry's work, although as time went on it became necessary in the interests of supply to study the details of certain figures such as those relating to wastage and repair. The detailed figures of production were at first obtained by numerous distinct officials in the supply, contracts, and inspection departments. Certain of the more important supply departments established statistical sections of their own. For instance, the Shell Manufacture Department was centred round a statistical section which furnished the nervous system of the whole organisation and was a definite administrative section, holding all the threads upon which the production of statistics and forecasts depended. The Controller of Shell Manufacture (Sir Glynn West) was indeed of opinion that " the gigantic organisation implied by War on the European scale must depend for its success amongst other things on a proper intelligence system, that is on statistics," and that these statistics should be not only compilations from pure figures but the outcome of an administrative branch which turns out figures as it were in its stride."[2] The preparation of estimates and progress records was a comparatively simple matter when they were concerned chiefly with the capacity and output of factories with which the supply officers were familiar. It became much more difficult as detailed figures of the materials to be used were required. This involved an intimate knowledge of manufacturing methods in individual factories, of the proportion of material to be purchased in different forms, for example, in the ore or as forgings, and of the quantity of scrap from different operations. When it became necessary to translate the manufacturing programme into terms of raw material or intermediate products, all these things had to be taken into account. When it was necessary to interpret the programme in terms of tonnage, the supply officer had to be prepared with statements as to the proportions of finished munitions, incomplete munitions, or raw materials, which were purchasable overseas.[3]

The decentralisation of statistical work throughout the Ministry threatened, in 1916, to make the records almost useless. The figures were obtained upon entirely different bases. They varied in their degree of accuracy and did not always cover every stage of production. Some were incomparable with others. Others again were mere duplications of figures obtained by a different department. At the end of 1916 it was realised that some more comprehensive scheme was needed

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[1] General Memorandum No. 12. For further details of the organisation, *see* Vol. II, Part I, Chap. V.

[2] Hist. Rec./H/1300/1.

[3] A.C. 34.

if it were only to enable licences for priority in manufacture or material to be granted along logical lines. Moreover, the comprehensive munitions programmes which were then just about to develop were entirely dependent upon reliable and uniform statistics.[1]

A special committee reported to the Advisory Committee in December, 1916, that the total requirements of all Government Departments and the Allies, when grouped together, should form the basis of the whole fabric of statistics. They recommended that a completely co-ordinated programme should be obtained by centralising the responsibility for correlating all statistics in the Department of Munitions Requirements and Statistics. When the complete programme had been produced, the progress of its fulfilment should be watched by means of weekly returns showing (1) forecasts of deliveries as far ahead as possible, (2) statements of forecasted supplies of materials against forecasted output of finished materials, (3) statements of forecasted supplies of materials against actual supplies, (4) statements of forecasted output against actual output, and (5) stocks in terms of weekly supply.[2]

The Advisory Committee thereupon recommended that detailed statistics should be kept on as simple a basis as possible, and in a form capable of being reproduced as graphs and superimposed to show the position of the various units making up the munitions programme, with due allowance for the necessary lag between operations; that responsibility for the compilation and circulation of each set of statistics should be definitely settled to avoid duplication; that D.M.R.S. should be supplied with the necessary information for compiling the complete statistics for the Ministry, and should be responsible for the collection and distribution of Army Council requirements and inter-departmental requirements such as those for raw materials, the classification of requirements into terms of urgency, the co-ordination of the finished statistics of the various branches of the Ministry into a statement showing the actual and prospective position in regard to supplies, for keeping in touch with the output of various departments as shown by the statistics, and for drawing attention to deficiencies or excesses; that each department's statistics should include figures showing their estimated programme for at least six months ahead; and that requirements should be forwarded by D.M.R.S. to the manufacturing supply department, where calculations of quantities of materials should be made, these calculations to form the basis of the raw material requirements which were to go through D.M.R.S. to the materials departments, who, in conjunction with the manufacturing supply departments, should report to D.M.R.S. what proportion of the requirements could be met. These recommendations were adopted. The machinery for putting them into effect was set up on 20 January, 1917.[3] A Central Statistical Conference was convened weekly by D.M.R.S. to co-ordinate the statistics of the various departments, and a Central Statistical Branch was formally established within D.M.R.S. itself.[4]

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[1] A.C. 34. [2] Report on Statistics to the Advisory Committee, 28/12/16. (A.C.34.)
[3] *See* Appendix I. [4] A.C. 34.

One of the main objects of this partial centralisation of responsibility for statistics was to provide the particulars for ascertaining the limiting factor of supply, so that it could either be remedied or the whole programme modified in order to obtain a properly balanced output. Another was to co-ordinate the whole of the statistical work of the Ministry. The machinery established in January, 1917, did not entirely effect these ends, and the subsequent grouping of the various departments for the purposes of the Munitions Council complicated the relations between the Controller of Munitions Requirements and Statistics and the various departments of the Ministry. A scheme for attaching statistical officers to each group to act as liaison officers between the Central Statistical Department and the statistical work done in the group, met with only partial success. It failed entirely where the groups were of composite character, as special knowledge of the technicalities of each branch of supply was essential.[1] Special arrangements were accordingly made in April, 1918, to meet the special circumstances of these groups; and the Central Statistical Branch was strengthened by the provision of specialist officers for particular supplies, following as far as possible the Council grouping. It was also definitely laid down that D.M.R.S. should be responsible for watching demands, and for this purpose should receive from supply departments regular reports as to the limiting factors in their several programmes. It was his special duty to bring to the Minister's notice every statistical tendency of importance.[2]

In fine, the Central Statistical Department had a dual function. It presented to the Minister the true position of each supply department, so that their various interests could be correlated. It drew the Minister's attention to any tendencies, favourable or unfavourable, so that these might be turned to good account or corrected, as the case might be.[3]

V. The Final Procedure in Programme Making.[4]

The procedure which was to be followed in making programmes was finally determined in May, 1918, when the art of programme making had fully developed. Establishment programmes, *i.e.*, the programmes of demand put forward by a Government Department for the supply or maintenance in the field of a given establishment, were to be agreed between the Department concerned and D.M.R.S., as the basis of action by the Ministry. The method of dealing with manufacturing programmes varied. The principal manufacturing programme was to be formulated by D.M.R.S., as was the programme for repair. Programmes for the more important components, such as fuses, were to be formulated by D.M.R.S. in conjunction with the supply department, and spares programmes in conjunction with the supply department as well as the Government Department concerned. Programmes for providing "details" to replace wastage during the inspection, proof

[1] Report of the Advisory Committee (Reference No. 5), 13 January, 1917 (A.C. 34).

[2] Hist. Rec./R/263.12/8.

[3] Hist. Rec./R/265/2.

[4] Hist. Rec./R/265/3; 263.12/9.

or testing of manufactured stores while still in the Ministry's charge were to be compiled by the supply departments and acted upon by contracts departments, reference only being made to D.M.R.S. in case of dispute. Before sending manufacturing programmes to supply departments for action, D.M.R.S. was to take into consideration all questions relating to stocks or wastage.

Materials programmes, arising from all the manufacturing programmes, except that for "details," were to be formulated by the departments responsible for the supply of the finished munitions or stores, and forwarded to D.M.R.S. for criticism and adjustment. After agreement, they were to be forwarded by D.M.R.S. to the materials departments for action. The total demands for materials were to be made by D.M.R.S. into materials budgets, upon which the materials departments would act. It was to be the duty of D.M.R.S. to see that the total programme requirement for materials was not exceeded month by month without special cause; but the supply departments were responsible for seeing that the material supplied for an individual contract was not accumulating at contractors' works. The supply departments were to indent weekly upon the Raw Materials Department for the provision of material to their contractors in accordance with the previous week's output from them. Copies of these statements were to be sent to D.M.R.S.

It was not considered necessary to submit programmes in respect of spot requirements which absorbed only small quantities of materials and made only small demands upon manufacturing capacity. Copies of all manufacturing programmes were to be sent to the finance and contracts departments at the same time that they were forwarded to the supply departments. These departments were also to criticise the allocation of orders upon manufacturing programmes. It was for the supply departments to draft schemes for allocating orders between home and overseas factories, in consultation with D.M.R.S., and also to draft the allocation of orders between national factories and private firms. It was to be the duty of the Contracts Department to distribute orders between the different firms.

The general programme, for which D.M.R.S. had thus prepared the details, was considered and interpreted by the standing Co-ordinating Committee of the Council, which took over the functions of the 1918 Programme Committee[1] in February, 1918, and eventually met under the Chairmanship of the Controller of Munitions Requirements and Statistics.[2]

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[1] *See* above, p. 17. [2] Vol. II, Part I, p. 185.

CHAPTER IV.

THE MAKING OF INDIVIDUAL PROGRAMMES.[1]

The gradual development of the general munitions programme has already been described.[2] At the first, it grew up as a series of isolated units defining the lines which were to be followed in regard to one munition or another. It is proposed here first to outline the forms which were taken by these numerous individual programmes, and afterwards to describe the steel and tonnage budgets into which they became merged.

I. Gun Programmes.

The earliest and most comprehensive programmes of the war related to guns and gun ammunition. In January, 1915, the army in France was provided with a forecast showing the output of ammunition which contractors had promised to deliver month by month until the following May. The figures were based upon contractors' estimates as recorded by the War Department. The contractors' promises were unfulfilled as regarded rate of delivery, and in April the gravity of the gun ammunition position gave rise to a new and balanced programme, which was formulated by the Master-General of the Ordnance under instructions from the Treasury Committee on the Munitions of War. This statement set out simultaneously the estimates of output and requirement. It gave, month by month, until the following August, firstly, the number of guns required and the deliveries of guns as expected, and secondly, the requirements of ammunition in rounds per week together with the number of rounds originally ordered and the numbers as then expected. From May until July, 1915, the statement of future gun and ammunition requirements passed rapidly through successive stages of elaboration.[3] In July, a programme[4] was drawn up which combined the War Office requirements for guns and ammunition to equip 70 divisions by the following spring, with the Ministry's information as to the restrictions in productive capacity which would limit their fulfilment. Towards the end of that month a second programme[5] was drawn up as a result of further inquiry into the supply position. The modified programme, which embodied the Ministry's revised estimates for equipping the 70 divisions, was accepted by the War Office as the final programme on 1 September. Meantime, Mr. Lloyd George had accepted the 100–division standard as the ideal of equipment for 1916.[6] Accordingly, the Ministry set up a new

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[1] This chapter is based mainly upon a statement drawn up by the late Mrs. F. Wood, an officer in the Department. (HIST. REC./H/1000/7.)

[2] *See* above, Chap. II.

[3] For the details of these early attempts at programme making, *see* Vol. I, Part I.

[4] Known as Programme " A."

[5] Known as Programme " B."

[6] *See* above, p. 2.

manufacturing programme,[1] which made special allowance for providing ample heavy artillery up to this standard, and allowed a large margin for wastage and repair. This increased programme for gun manufacture was accompanied by a correspondingly increased programme for supplying ammunition. Mr. Lloyd George was convinced that the surplus orders for heavy artillery would not in the end exceed the requirement of the British armies; but the increased scale of production also had a secondary use in making it worth while for firms to lay down the costly plant which was necessary for the early deliveries needed for the 1916 campaign. The War Office questioned whether the *personnel* would be available for putting the guns into the field, but the increased programme was finally confirmed by the Government.[2]

Although the size of the British armies was not brought up to the 100-division standard, the experience of the 1916 campaign led to large increases in the demands for guns, and especially for heavy artillery, for it became more and more important to be able to develop a superiority of heavy artillery at the point of attack without transferring numerous guns from other parts of the battle front. In July, 1916, the demand put forward from France covered (*a*) a strength which it was essential to reach before the 1917 campaign began and (*b*) the strength which should be attained as soon as possible thereafter.[3] The difficulties of manufacture, and especially the provision of skilled labour and machining capacity, were, however, so great that it was not until the 1918 offensive that the War Office demands for establishment and reserve put forward in July, 1916, "to be ready as soon as possible," were met for all natures. Meantime, the work of programme making for guns chiefly consisted in seeing that the gun and carriage programmes were correlated and that the required number of breech-mechanisms, recuperators, etc., were forthcoming. The manufacture of carriages was particularly difficult, and seriously limited supply almost till the end of the war. So long as the vast bulk of the manufacture was for new equipments, the necessary calculations were comparatively simple. In the autumn of 1916, as the effects of the increased rate of fire began to tell upon the guns,[4] it became necessary to prepare much more elaborate gun programmes. Arrangements had to be made for repairing worn guns and carriages on a largely increased scale. To a certain extent the repairing capacity had to be provided at the expense of the manufacturing capacity, and thus it became of first-class importance to have reliable estimates of probable wear during the future.

From February, 1917, onwards extensive calculations were made of the probable "life" of the various equipments.[5] The War Office expressed their demands in terms of a requirement for establishment and reserve, and a statement of their ammunition requirements. From these data the estimated wear casualties were then calculated in the Ministry. Estimates of the casualties from shell fire and prematures

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[1] Known as Programme "C."

[2] For the details of these programmes, *see* Vol. X, Part I.

[3] *Ibid.*

[4] *See* above, p. 8.

[5] For the methods used, *see* Appendix II.

were also made, based upon past experience, and gun and carriage programmes were then prepared giving (*a*) the required output of new equipments to meet the War Office demands for establishment and reserve, to replace non-repairable casualties and to provide the required "pool of spares" to replace equipment undergoing repair, and (*b*) the required repair capacity for dealing with the repairable casualties.

II. Gun Ammunition Programmes.

The importance of the gun ammunition programme can scarcely be exaggerated since it occupied by far the greatest part of the whole programme for munitions, whether calculated in items of men, money, materials or shipping facilities. The programmes for guns in 1915 governed the arrangements for gun ammunition. A programme of weekly shell output was thenceforward formulated on the basis of the daily ration per gun, as stated by the War Office, and changes were made from time to time in the proportions of the different natures and of high explosive, shrapnel, and miscellaneous shell.[1]

Since the creation of manufacturing capacity for the empty shell was the main problem which faced the Ministry in the summer of 1915, the early supply programmes were based mainly upon the provisions made for shell manufacture. Little or no allowance was made for the time which would be occupied in such operations as inspection, changes in design, or the provision of components, while the period which would pass before new filling capacity could be established was entirely problematical, since the methods to be used in filling many natures were still undetermined. During the autumn of 1915 these other factors threatened one by one to overthrow the whole programme of supply. First the gaine, then the primer, then the arrangements for filling gaines, then the detonator, and later the fuse-filling arrangements held up the final supply of complete rounds.[2] Prematures and blinds with high explosive ammunition in the field also made it certain that the pattern of these components must ultimately be changed; but the final settlement of the design was slow in coming and was seriously hampered by the divorce between design and supply authorities.[3] Towards the end of the year, instead of the expected increase in H.E. ammunition there came a general falling off.[4] These difficulties were overcome early in the year 1916. The new design authority, which was set up in the Ministry, in December, 1915, solved during a month or two of concentrated work those problems relating to detonation and methods of filling, which had delayed the whole programme of supply since the previous September.[5] The importance of watching carefully all the stages of production became apparent. Measures were taken to keep track of every process, the manufacture of the empty shell, the manufacture and filling of each component, and the provision of explosive.[6] The forecast of supply was for a

[1] For the details of these programmes, *see* Vol. X, Part II, Chap. I.
[2] Hist. Rec./H/1300/1. Enclosure B.
[3] *See* Vol. IX, Part II, Chap. IV.
[4] C.R. 3008.
[5] Vol. IX, Part II, Chap. V.
[6] For the methods used to secure a balancing of components, *see* below, p. 42.

time based upon the pace of the filling factories, which were responsible for the completion of the round, and were peculiarly susceptible to the effects of any failure in the long succession of operations, which go to produce a single round of ammunition.[1] Up to the end of 1916 the filling of shell kept pace with manufacture, and the two programmes for the empty and the filled shell were nearly identical. Thenceforward, the stocks of shell and components were built up to provide against emergencies and to aid in balancing the output of components.[2] The danger of holding enormous stocks of filled shell restricted their accumulation. The programme for filling thus became subject to seasonal fluctuations, rising during the battle period and falling during the winter months,[3] while manufacture of metal parts was carried on more evenly in order to avoid industrial disorganisation.

By the end of 1916 the productive capacity of the country had reached such a size as to be able to supply the whole of the War Office requirements, largely increased as they were; but the practice of allowing a margin of 20 per cent. upon the supply programme, as an insurance against contingencies, was then abandoned. In February, 1917, it became apparent that the output of guns and the capacity for repairing guns was not large enough to enable the whole of the War Office ammunition programme to be fired. It was in consequence reduced until it was correlated with the gun programme.[4]

The prospective output of guns for 1918 was such as to enable the whole of the original War Office ammunition programme to be fired, but a series of reductions had to be made for various reasons. In the first place, it was found that transport across the Channel could not be provided for the whole of the programme as originally planned, neither could the ports on the French side deal with such vast quantities of shell. A first reduction was therefore made to bring the average weight of all munitions to be transported to Havre down to 31,000 tons a week during the winter, and 45,000 tons a week during the summer. Shortly afterwards the general overseas tonnage position became critical, and the tonnage allocated for the importation of munitions and their materials was reduced from 15,000,000 tons to 10,000,000 tons per annum. This led to a serious reduction in the import of Spanish iron ore, a shortage of steel available for shell manufacture and a further reduction in the ammunition programme. The situation was relieved to a certain extent by purchases of steel and pig iron in America, and by the fact that the tonnage position improved and larger quantities of Spanish ore were imported than had been anticipated. Thus, although the home output of steel did not reach the anticipated figure, no further reduction was made in the ammunition programme. In fact, the gun ammunition programme which was made in April, 1918, after the German offensive, taking the programme as a whole, effected a substantial increase.[5]

[1] Vol. X, Part V, p. 5.
[2] *See* below, Chap. V.
[3] Vol. X, Part V, pp. 73–74.
[4] Cf. below, p. 41.
[5] For the detailed account of these programmes, *see* Vol. X, Part II, Chap. I.

III. Programmes for Machine Guns, Rifles and Small Arms Ammunition.

(*a*) MACHINE GUNS.

The main feature in the demand for machine guns was its rapid development. Not only were new guns needed to equip the new armies and replace casualties, but the scale of establishment was first doubled, then quadrupled, and then doubled again. From 1914 until 1917 the programme was determined only by this scale of establishment, and manufacturing arrangements were made to supply the maximum number of guns which could be obtained to meet this scale and to provide for a fixed percentage of casualties.[1] In the autumn of 1917 the preparation of a more comprehensive programme became a matter of absolute necessity, as the aircraft programme, on the one hand, and the tank programme, on the other, demanded large numbers of machine guns for armament and threatened to starve the supplies for the land force. By that time the land forces were equipped according to the then existing establishment, and the output had merely to cover wastage and provide a small supply for the Allies. The programmes of the tank gun (Hotchkiss) and the air type guns were ultimately based on the estimated output of tanks and aircraft respectively, the aim being to provide sufficient machine guns to equip fully all tanks and aeroplanes produced. In addition, a certain production was necessary to replace wastage and provide a sufficient reserve.

After the German offensive of 1918 the War Office decided to increase the establishment of machine guns for the land forces. In addition, losses to the extent of about 4,000 machine guns had to be made good. Fortunately, there was a fair reserve of land-type guns in existence, and a further supply was obtained by converting air-type guns, of which a considerable surplus had accumulated since the programme for aircraft manufacture had not been fulfilled.

(*b*) RIFLES AND SMALL ARMS AMMUNITION.

The rifle programme was based on the establishment of one rifle per man, and the demand accordingly developed rapidly with the growth of the new armies.[2] The manufacturing programme was based upon the acquisition of all the rifles available until the entire force was completely armed, after which the bulk of the requirements were to replace wastage.[3] Data of wastage were ample and comparatively easy to collect; although they were variously affected by the inconstant number of rifles, which was in use.[4]

Until the summer of 1916 the programme for standard small arms ammunition (·303-in. Mark VII), was based upon an assumed expenditure of four rounds per man per day for 80 per cent. of the Expeditionary Force, fixed numbers of rounds per rifle for the new armies and for reinforcements. Machine guns had an initial allowance

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[1] Vol. XI, Part V, Chap. I.
[2] *See* above, p. 2.
[3] For the details of the requirement, *see* Vol. XI, Part IV.
[4] Mr. Layton, before the Advisory Committee, July, 1917, (A.C. 120.)

of 50,000 rounds per gun and a subsequent supply of 10,000 rounds per gun per month. In September, 1915, the War Office requirement from July, 1916 onwards, was formulated as 300,000,000 rounds per month, and a corresponding manufacturing programme for 400,000,000 rounds was arranged in order to provide supplies for Russia. Thenceforward, the demand fluctuated very considerably with actual experience in the field. Ultimately it was calculated that certain classes of operation involved a certain average expenditure; but the programme remained subject to sudden change. The actual monthly expenditure during 1916 was considerably less than the 300,000,000 rounds originally required or even than the 200,000,000 rounds to which this was reduced in July, 1916. Stocks were accumulated and the manufacturing programme reduced or suspended. By the end of 1917 reserves had fallen low and the expenditure had for some months exceeded output, while the tendency was for the demand to increase steadily. A new and enlarged programme was accordingly formulated for the first four months of 1918, in order to rebuild the reserve, and was again enormously increased for the remaining months of 1918, in order to make good the losses of the German advance and to establish a new reserve.[1]

IV. Programmes for Trench Warfare Stores.

The requirements for such novel equipment as trench warfare stores were necessarily determined empirically. The programme of supply was governed for nearly eighteen months by questions of design. The number of mortars to be provided was restricted during this period by the amount of ammunition which could be made.[2] The first patterns to receive sanction for bulk manufacture at home were of a complex nature, only capable of manufacture by skilled labour and on plant similar to that which was needed for guns and gun ammunition. In particular, the fuses both for bombs and grenades were either those which were already in large demand for important natures of shell or were of equally complex design. The need for encroaching upon normal munitions capacity thus seriously hampered the development of a trench warfare supply programme.[3]

Regarded as emergency stores, the chief use of trench warfare supplies was to bridge over the period occupied in building up productive capacity for munitions of standardised kinds. This function they fulfilled scarcely at all, by reason of the design difficulties which have been described. It was not until responsibility for design had been transferred to the Ministry in December, 1915, that the essential simplicity of the trench mortar as distinct from ordnance was fully recognised. The introduction of simple patterns capable of manufacture by comparatively unskilled labour and upon ordinary engineering plant followed almost immediately; but this development was almost concurrent with the full development of manufacturing capacity for guns and gun ammunition, and the large programme undertaken in 1916 was in consequence reduced as the war went on.

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[1] *See* above, p. 7; for the details of these programmes, *see* Vol. XI, Part VI, Chap. IV.

[2] *See* above, p. 3.

[3] Vol. XI, Part I, Chap. I.

In October, 1915, the establishment for light, medium and heavy trench mortars had been fixed on a divisional basis and the ration of ammunition was determined according to firing capacity. To the existing demand from the War Office, Mr. Lloyd George had then already added 1,000 Stokes mortars with their ammunition, since this was a type which could be more easily supplied. The Stokes mortar was included in War Office requirements in November, 1915; but difficulties with the fuse design were not overcome until the following March. Thenceforward, the chief features of the programme for these stores were, firstly, a reduction in the number of different types with a view to facilitating training and supply, and, secondly, a steady reduction in the quantity of ammunition provided in order to avoid congestion in the trenches.[1] The decrease in the use of trench mortars as the war progressed was not anticipated, and in consequence there was a certain over-production of bombs in 1917. The stocks which had accumulated by March, 1918, were thus more than sufficient to cover British losses in the German advance. With the development of open warfare, demands for trench mortar ammunition ceased altogether.[2]

The programme for grenades was peculiarly subject to fluctuation, which was ascribed to changing circumstances in the field because of unexpected conditions.[3] The weekly demand for the most common type would, for instance, rise from a quarter of a million to nearly a million and a half and fall again suddenly, as it was found that expenditure fell below expectation. The very extent of the numbers needed added to the practical difficulties experienced in estimating past use as a basis for future requirement. The problem was aggravated by the novelty of the weapon, by changes in design, and by the introduction of new types.[4]

V. Chemical Warfare Programmes.[5]

The early demands for chemical warfare supplies were even more empirical than those for trench warfare stores; but the demands for trench warfare stores became comparatively stable with the development of experience in the conditions of siege warfare, while those for chemical warfare supplies were never freed from change.[6]

Under such conditions the final programme was peculiarly dependent upon the results of research and the possibilities of manufacture, and until August, 1916, there was little attempt to formulate a numerical forecast of demand or supply. The suddenness with which the requirement for the more lethal mixtures was laid before the manufacturers in the spring of 1916, made it impossible to fulfil the immediate demands, and from August, 1916 onwards, programmes[7] for chemical projectiles were formulated on a regular, weekly basis; but the requirement for cylinder gas continued to take the form of "spot" demands until August, 1918, when the programme for these also was put on a weekly basis for the 1919 campaign.

[1] For the details of these demands, *see* Vol. XI, Part I, Chap. III.
[2] *Ibid.* p. 69. [3] *Ibid.* p. 3. [4] *Ibid.* p. 88.
[5] *See* Vol. XI, Part II. [6] *See* below p. 46.
[7] These programmes are given in Vol. XI, Part II, Appendix II.

The main feature of these programmes was their steady advance at a rate which was enormously increased in 1918. In August, 1916, the programme was for a supply of 112 tons of chemicals weekly in four different natures of projectile, exclusive of cylinder gas. By the spring of 1918 the programme for that year had reached a total of 350 tons weekly in five different projectiles. The formal requirement for the 1919 campaign, as laid down in August 1918, provided for 795 tons weekly in ten different natures of projectile, and the actual programme of supply was unlimited, except so far as it was restricted by grave practical difficulties in manufacturing and handling the extremely poisonous mixtures then required.

VI. Mechanical Warfare Programmes.

The preparation of programmes for the various mechanical devices used in warfare had certain common features which grew out of the complex nature of this kind of supply. In each case the main problem was one of correlating the production of numerous parts and balancing the supply of armament or equipment with that of the machine or vehicle. In each case there were additional problems arising firstly from the need for providing spare parts to replace those which were most subject to wear and tear, and secondly from the difficulties of arranging for a programme of repair alongside a programme of new production. In these respects the methods of formulating a programme for tanks or mechanical transport vehicles resembled closely those which were used for guns and gun carriages. Further difficulties arose from the common demand made by mechanical transport vehicles, tanks and rolling stock upon a single class of productive capacity, so that the programme for their supply was governed by such factors as the allocation of stampings, or the capacity of the shops for making and repairing railway material or internal combustion engines.[1]

(*a*) Mechanical Transport and Railway Materials.

It has been seen that there was no fixed establishment for mechanical transport vehicles until the last year of the war.[2] Even then no satisfactory estimate could be made of the capacity needed for spare parts, whilst the general balancing of the programmes for manufacture and repair was impracticable, because of the division of authority, as the War Department remained responsible for repair and the Ministry of Munitions for supply.[3]

Similarly, no completely comprehensive programme was formulated for railway materials. The demands made upon the Ministry related to the military needs overseas; separate arrangements were made by the War Office for supplying military needs at home.[4] Definite numerical requirements for overseas track and rolling stock were received from time to time after the general survey of transport facilities in 1916;[5] but no means existed for correlating the programme of manufacture with that of repair.

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[1] For the general account of these problems, *see* Chap. V, below.

[2] *See* above, p. 5.

[3] Vol. XII, Part IV.

[4] Vol. XII, Part V, pp. 7–9.

[5] *See* above, p. 5.

(*b*) Tanks.

In 1916 tanks formed an entirely new arm, and there was no standard by which to fix initial requirements or the provision of spare parts. The first demand was fixed in February, 1916, at 100 machines, to be ready for their first use in the summer, and additions were subsequently made with a view to continuity of output. Nevertheless, the difficulties of supply were so great that barely 50 machines took part in the first surprise of September, while the programme of manufacture was thenceforward hampered by the need for providing spare parts[1] and for arranging for modifications in the design.[2]

During the winter of 1917 and during 1918 the repairable and non-repairable wastage of tanks was studied, and the War Office prepared a scheme of establishment for tanks. The preparation of a manufacturing programme to cover repairable and non-repairable wastage and to provide the new establishment required was very similar to that for guns and carriages. Care had to be taken that there was a proper relation between the various parts of the tank, e.g., hull, sponsons, etc., and somewhat elaborate calculations had to be made in order that the armament programme (Hotchkiss machine guns and 6-pdr. and 2-pdr. guns) should be correlated with the tank programme.

During 1918 a scheme was started for the joint production by the United States of America and this country of 1,500 tanks, Great Britain providing armament in addition to hulls. Later in the year an attempt was made to prepare a series of tank programmes for all the Allies and to concentrate the manufacture of particular types of armament in different countries, the country in question to manufacture for all the Allies. This scheme was in the making when the Armistice was declared.

VII. Aircraft Programmes.

No really comprehensive programme for naval and military aircraft existed until March, 1917. Previous to that date each Service had made its own calculations as to demand and supply, and such programmes as did exist were mainly estimates of possible supply,[3] for the strictly limited extent of the productive capacity made the supply of aeroplanes a governing factor in the expansion of the air forces.

The establishment of aircraft squadrons had been fixed before the war, but it changed rapidly both in the number and in the nature of the machines as the use of aircraft developed. Thus the equipment of a squadron ultimately varied according as it was intended for fighting, reconnaissance and defence, or bombing. The comparatively simple pre-war demand of 12 machines per squadron thus developed by September, 1918, into an establishment for different classes of squadron of 24 reconnaissance machines, 25 fighters, 12 twin-engined bombers, 18 single-engine day bombers, a varying number of night bombers according to the type used, 10 large boat seaplanes, or 18 small seaplanes. Alongside the programme for complete aircraft, it was necessary to calculate a distinct programme for the production of

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[1] *See* below, p. 43. [2] *See* Vol. IX, Part II, pp. 104–105.
[3] Mr. Layton before the Advisory Committee, 30 July, 1917. (A.C. 120).

engines, of which a large surplus was needed for use during repairs. Frequent changes in type made it essential to arrange a margin of supply to cover technical difficulties and constant changes in design, while consequent over-budgeting was successfully avoided through close relation between the service and supply officers. Wastage was extraordinarily heavy. The aeroplanes of an active squadron needed replacing about once a month, and the wastage resulting from crashes, involving both aeroplane and engine, was estimated during an active period at 15 to 20 per cent. of the active machines per month. This wastage was, however, greater for the aeroplanes than the engines, and the two rates of replacement had therefore to be calculated on different bases ; while a further allowance had to be made for different rates of repair for the rotary, air-cooled and water-cooled engines.[1]

VIII. Steel and Tonnage Budgets.

By the end of 1917 the demand for steel for all purposes, particularly for the Admiralty and for the manufacture of munitions, had become so large that, generally speaking, the limiting factor in the production of munitions had ceased to be the machining capacity of the country and had become the steel supply. In these circumstances a steel budget was prepared giving the ration allowed for each main store or manufacture, e.g., Admiralty, gun ammunition, tanks, War Office stores, Allies, industry, etc. The budget was prepared by taking, in the first instance, the amount of steel stated to be required to carry out the existing programmes, and scaling these figures down until the total came within the estimated supply. A simple *pro rata* reduction was not made, the relative importance of the different programmes being taken into account. Thus, the Admiralty demand was met in full, as was the demand for aircraft and tanks.

The production of steel was regulated by the facilities for shipping iron ore, which constituted more than one-half of the imports on munitions account. Immediately after the preparation of the first steel budget in January, 1918, the general shipping position had become such that a drastic reduction in the imports into the country during 1918 seemed inevitable. Accordingly, the Shipping Controller proceeded to ration the various Departments requiring overseas tonnage, e.g., Ministry of Munitions, Ministry of Food, Board of Trade, etc. In the first instance, the Departments prepared shipping budgets in accordance with their existing programmes, and these were scaled down by the Shipping Controller in consultation with the War Cabinet until the total allocation did not exceed the estimated total available. Again, a *pro rata* cut was not made, but the various demands were reduced according to the relative importance of the various programmes.

As a result the tonnage available for munitions purposes was reduced from a total of 15,000,000 tons to 10,000,000 tons. Fortunately, this did not involve a proportionate reduction in the output of munitions. The original 15 millions budget was a generous one and would have enabled considerable stocks of raw materials to be built

[1] For the details of these programmes, *see* Vol. XII, Part I, pp. 67–75.

up by the end of 1918. Further, in many cases it was proposed to use up a portion of the stocks then existing, and, as far as possible, arrangements were made for the materials to be carried in the least bulky form. Thus iron pyrites from Spain was replaced by sulphur and so forth. The shipping position during 1918 was considerably better than anticipated, and the actual imports on munitions account during that year amounted to 11,881,297 tons.

Both a tonnage budget and a steel budget for 1919 had been prepared at the time of the Armistice, and in both cases this had been done in consultation with the Allies, and formed part of the inter-allied budgets for Great Britain, France, the United States and Italy, which had been approved by the Inter-Allied Munitions Council. No tonnage budget for the United States was prepared, as their tonnage was exclusively for the coasting trade, of which they had control of the ships, and for the carriage of troops to Europe, which was not under the jurisdiction of the Inter-Allied Munitions Council.

CHAPTER V.

THE MAIN PRINCIPLES OF PROGRAMME MAKING.

I. Methods of Watching Progress.

It would not be practicable to attempt here any exhaustive treatment of the various methods in actual use for measuring the progress of munitions supply during the war. The uses of the various forms in which figures were available may, however, be illustrated by the following comparisons of figures relating to some aspects of gun ammunition supply.

(a) Comparison of Output with Programme.

It was at all times exceedingly difficult to obtain a just knowledge of how far current production was actually meeting requirement. The complex and shifting nature of the programme made it impossible to gain more than a very rough notion from a simple statistical record, such as that shown in Appendix III. Some idea of the modifications to which the programme was subjected from time to time will be gained by comparing the first two columns at each date, the one denoting the programme as estimated four months or more ahead; the second in each case showing the actual demand at the date when production is shown in the third column. This table also serves to show the stages by which production was brought up to the level of the programme, and by the use of the average weekly figure of production over the months in question it represents something more than the actual position at an arbitrarily chosen point of time. The figures for March, 1916, show that the production of every nature of shell was then considerably in arrear. Those for the following June showed how the newly created capacity was rapidly remedying this position. The rate of filling the lighter natures of shell had then very nearly reached the programme figure; the rate for heavier natures was approaching more nearly to the programme figure than it had been three months before. The same statement for 1917 shows the full effect of the output from the new capacity. The two curves of programme and output were not absolutely coincident, but they had approached each other much more nearly.

(b) Comparison of Deliveries, Stocks, Issues and Expenditure.

The actual progress of supply could be watched in detail by means of tables which showed the current rates of manufacturing and filling for each component of the complete round, and the stocks which existed at each stage in the operations. Examples of these tables are given in Appendix VI, and their uses will be discussed later.[1]

[1] *See* below, p. 42.

Another and less elaborate system is shown in the tables given in Appendix IV. These relate to some of the principal natures of shell only, and the figures are given yearly from 1916 to 1918 in order that the whole period for which these returns were kept may be covered at a glance. The rate of manufacture is denoted by deliveries of the main component only, the empty shell. The figures of empty stock show how manufacture was consistently ahead of filling. The rate of filling represents the rate of final production, and a comparison of this figure with that for issue shows how rapidly the completed ammunition was transferred from the Ministry's factories to the custody of the War Office. Filled stock is generally less than empty stock. A comparison of the rate of expenditure for any year with the rate of issue shows roughly how far supply was keeping pace with consumption, and a comparison of the stock at the end of each year with the current rate of expenditure denotes the period for which a reserve was available.

II. Relative Urgency.

(a) Arrears as the Test of Urgency.

At first, relative urgency was chiefly determined by the amount of the existing discrepancy between demand and supply. During the first eighteen months of the Ministry's existence it was taken for granted that the supply of all munitions was among the most urgent of the country's needs. Supply departments from the first took steps to secure the preferential treatment of their direct contractors and, in certain cases, of their sub-contractors also. In February, 1916, the Priority Branch of the Ministry was definitely authorised to instruct firms as to the relative urgency of their war work, so that they should not receive conflicting orders from different departments of the Ministry. In March, 1916, a definite system of permits in order of urgency was established. Under this scheme controlled establishments received certificates notifying that their contracts were classified either as (A), (B), or (C), according to whether the work was direct war work, necessary for the efficient prosecution of the war, or civil work. Controlled establishments were simultaneously authorised to inform their sub-contractors that the orders placed with them had the same classification as the direct contract. A Priority Committee which had been established within the Ministry since September, 1915, advised the Priority Branch, acting on information from the various supply departments which it represented. It also advised the Labour Supply Department in transferring labour, and gradually compiled a list of firms in their order of priority for labour. This Committee gradually added to its numbers representatives from the Admiralty, War Office, and other Departments of State, and worked also through several sub-committees, such as the Railway Priority Committee.[1] Early in 1916, D.M.R.S. began to compile a monthly report on the "extent to which War Office requirements are being and are likely to be met" . . . "with a view to affording some guidance as to the relative urgency of various munitions."[2]

[1] Hist. Rec./H/620/6. For a more detailed account of the development of the priority system, *see* Vol. VII, Part I, Chap. IV.

[2] (Printed) *Weekly Report*, No. 32, X (4/3/16); Hist. Rec./R/620/11.

(b) METHODS OF CORRELATING PROGRAMME MAKING WITH THE PRIORITY SYSTEM.

The priority scheme, which was established in March, 1916, excluded any arrangements for priority in the production or distribution of materials, which were then in a comparatively satisfactory position. By the end of the year the shortage of materials had become so acute that the whole organisation for dealing with priority was considered by the Advisory Committee in the light of the materials position, with a view to co-ordinating the decisions of the Priority Branch with the position of supply and demand in the munitions programme.[1] The question was considered alongside that of the measures for co-ordinating statistics within the Ministry, which have already been described,[2] and in reorganising the administration in respect to priority it was decided that a statistical officer from the Department of Munitions Requirements and Statistics, who was informed of the general position of munitions requirements and supplies, should become a member of the Ministry's Priority Committee.[3]

The difficulty of allocating productive capacity to the various classes of munitions was also growing as the munitions programme became more and more complex and as the general stringency became more and more pressing. In June, 1917, a deadlock arose from the fact that at least six different supplies had been given equal first-class priority.[4] One of the chief difficulties came from the necessity for deciding as to the relative urgency between the manufacture of spares or of complete munitions.[5] From June till November, 1917, these questions were determined by an Allocation of Urgent Supplies Board. The members of the Board represented the various supply and contracts departments and the Priority Department of the Ministry, and the representative of D.M.R.S. acted as secretary. Its duties were concerned with the allocation of certain factories to the sole production of supplies of the highest class of priority, the settlement of conflicting claims upon productive capacity, and the allocation of manufacturing capacity between the production of spare parts and of complete munitions.[6]

Meantime, with the restrictions in shipping, the munitions programme had taken second place in the general programme for maintaining the country's supplies of food, warlike stores, or essential industrial products. The relative urgency of the different warlike stores was also becoming too wide a question for settlement by the Ministry in consultation with the War Office. Some higher authority was needed to lay down the general policy as to the production of ships or aeroplanes, tanks or railway material. Such an authority was set up when the War Priorities Committee of the War Cabinet was established in September, 1917.[7] Thereafter, D.M.R.S. continued to compile a monthly report on the relative urgency of munitions,

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[1] A.C. 42.
[2] *See* above, p. 23.
[3] A.C. 42.
[4] HIST. REC./R/1000/108.
[5] *See* below, p. 43.
[6] General Memorandum No. 9. (8/6/17).
[7] It was superseded in October, 1918, by the Joint Priority Board, *see* Vol. VII, Part I.

which was, however, submitted to the War Priorities Committee before issue. At the same time the Allocation of Urgent Supplies Board was dissolved, and special officers were appointed to keep each member of the Munitions Council posted as to the decisions of the War Priorities Committee, as well as to keep in touch with D.M.R.S. as to the relative urgency of various munitions.[1]

(c) The Allocation of Resources among different classes of Munitions.

All these arrangements included special measures for securing the allocation of labour to the more urgent purposes of the war, since labour was a factor which actually limited many of the activities of supply. In considering the programme of demand, it was not, however, considered practicable to take into quite the same account the best methods for allocating the country's wealth. Neither finance, contracts nor accounts, were represented on the Programme Committee of the Council, for it was considered that labour, machining capacity, and materials limited the programme long before it was restricted by financial considerations; but the arrangements for making the programmes for individual supplies established in May, 1918,[2] gave to these financial departments important duties in criticising individual manufacturing programmes.[3]

From December, 1917, however, the question of cost was taken into general consideration along with the supply of labour, material and tonnage. In making his decisions as to programme, the Minister had before him a graphical representation based upon figures similar to those given in Appendix V. This showed at a glance the comparative cost of the different munitions for which provision was being made on the basis of a fixed allocation of the tonnage which was available for munitions. It gave, also, the relative quantities of the main material, steel, which would be required for the various classes of munition upon this distribution of the tonnage, and a similar picture of the numbers of operatives which would be needed. From time to time the Minister urged that preference should be given to the demand for those munitions which would use to the best effect the country's depleted resources. For instance, in November, 1917, he advocated the increased use of mechanical means for supporting the country's man-power, the discharge of high explosives, for which manufacturing capacity was still abundant, from aerial bombs, which needed less steel than gun ammunition, and the increased use of the trench mortar, which was comparatively easy to produce.[4] Again, he constantly urged that preference should be given to the use of tanks rather than gun ammunition, as a means of preliminary attack, since the demands made by the tank upon the steel budget, which was limiting all supplies, were relatively small.[5] The military position necessarily controlled the final decision in these

[1] Hist. Rec./R/620/24. [2] *See* above, p. 24.
[3] For the details of this development, *see* Vol. III, Part I, pp. 117–125.
[4] Memorandum on Munitions Possibilities of 1918 (21/10/17) (Hist. Rec./R/1000/88).
[5] D.M.R.S. 555.

cases, but there was a steady tendency towards giving preference to those munitions which could be most readily produced. This tendency showed itself most remarkably in the increased use of such novelties as chemical shell or tanks.

III. The Balancing of Output.

One of the chief difficulties in formulating programmes was to maintain an even balance between the production of one munition and another, between the manufacture of the various parts of the same munition, between the manufacture and repair of various munitions or between the production of complete new munitions and their spare parts.

(*a*) THE BALANCING OF ONE MUNITION WITH ANOTHER.[1]

Decision as to which munitions should be made was primarily the duty of the military authority responsible for the programme of demand; but the final programme depended so largely upon the possibilities of supply, that the tendency was for the Ministry of Munitions to take an increasing interest in this side of the compilation of programmes.

The Ministry experienced special difficulty in securing a balance between the output of guns on the one hand, and of ammunition on the other. This difficulty arose, in the first place, from lack of knowledge as to the time it would take to produce the one or the other. In the second place, the balance was disturbed by unforeseen interruptions in one or other of the processes of production. Thirdly, the demand itself became unbalanced by unexpected changes in the rates of gun wastage or ammunition consumption.

Until the summer of 1916 there was a great shortage of ammunition, although the number of guns was large, and the ration per gun was comparatively small. Moreover, the new guns, produced during the early part of the war, had their full life before them. In the summer of 1916 there was accordingly an accumulated capital of firing capacity. Thenceforward, the output of gun ammunition rose rapidly enough to alter the balance in the opposite direction. Arrangements which were made for repairing guns in the autumn could not bear full fruit, because the reserve of guns in France was still too small to allow of the building up of a large enough stock of repairable guns to keep a great repairing organisation in continuous output. The transfer of gun manufacturing capacity for the arming of merchant ships in December, 1916, weighed down the scale still further on the side of ammunition production, and in the summer of 1917 the output of ammunition exceeded the firing capacity in the case of several important natures. The curtailment of the gun ammunition programme on this score was, however, lost in the still greater reductions necessary on account of the tonnage and steel position.

Very similar problems arose from the need for synchronising the equipment or armament of such munitions as tanks or aircraft with

[1] C.R. 4383.

the machines themselves. It sometimes occurred that the whole supply programme of such stores was restricted by difficulty in producing the necessary armament, and only a very careful control over the production of multifarious details secured the simultaneous completion of the entire machine with all its equipment.[1]

(b) The Balancing of Components.

From the time when munitions contracts began to be spread among numerous factories, the normal problem of balancing the output of the various parts, and synchronising all the operations which went to make a complete article, became exceptionally difficult. It was largely due to the failure of sub-contractors to keep pace with direct contractors that deliveries of gun ammunition fell behind in the spring of 1915. One of the first duties of the Ministry was to balance the new capacity for shell manufacture, component manufacture and shell filling and assembling, as it came into action in the spring of 1916.

In order to obtain a complete survey of the supply position and to forecast the future rate of delivery it was necessary to watch the rates of manufacturing cartridge cases, primers and tubes, fuses and gaines, as well as shell cases, and to compare these with the rates of filling these various components, and finally with the filling of the shell and the completing of the round. The whole question was complicated by the allocation of various types of components to different natures of shell. Moreover, the filling of each component and the completion of the round themselves entailed the synchronised assembling at the filling factories of these numerous components, together with various quantities of miscellaneous textiles and other materials. Thus the problem became one of transport and storage as well as of manufacture. The whole country had, as it were, become a gigantic factory for producing ammunition, and the balancing of its varied operations was as much the criterion of success as is the balancing of output from the different units in a well-managed factory.[2]

Until February, 1916, interest centred round the output of the empty shell, and little attempt was made to compare the growth of the new machining capacity with the simultaneous development of filling arrangements or with the rate of component supply. For the time, shell and explosives ran far ahead of their components and of filling capacity. Comparative statements showing progress in all its details were first compiled for the week ending 5 February, 1916, as part of a definite effort to synchronise all the operations of supply. A summary of the first of these balance tables is produced in Appendix VI. This table showed at a glance the enormous discrepancy between the position of empty shell and that of the filled ammunition. It showed that empty cartridge cases were seriously in arrear of the corresponding shell, and that other components were in a fairly satisfactory position, with the exception of gaines and fuses. Owing to recent changes in design, the position of the filled gaine was particularly serious.

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[1] *See* above pp. 34–35.
[2] *See* Vol. X, Part V, pp. 5, 47.

(c) COMPLETE MUNITIONS OR SPARES.

In many instances the programme for component manufacture had to take into account not only the synchronised production of many parts to produce a complete whole, but also the provision of spares to replace those components which were most subject to casualty or wear. In some cases it was a comparatively simple matter to estimate the proportion of extra components which would be so needed. Thus the pool of rifle components which was established in 1915 made allowance for the new rifle programme together with a certain proportion of spare parts, based upon the experience of the Ordnance Factory in repairing rifles. In other instances no satisfactory method of estimating the numbers and natures of the spares which would be needed was found during the war. The most notable example is that of mechanical transport vehicles. Manufacturers were accustomed to make complete vehicles and to keep in stock a certain proportion of the spare parts which were most subject to wear in time of peace; but the peace-time demand for spares bore no relation to the demand in time of war when all vehicles were subjected to peculiar strain. Although stocks were accumulated of the spares for which the largest demand was expected, it was quite impracticable to estimate accurately what proportion of each would be required for each of the various types of vehicle in use. Hence, the requirements for spare parts were rarely met in full. Towards the end of the war, as the demands for mechanical transport increased, this question developed into one of priority between the manufacture of complete new vehicles and the maintenance of those already in service.[1]

(d) MANUFACTURE OR REPAIR.

The programme for manufacturing spare parts depended very largely upon the programme for repair, and it was partly because responsibility for the repair of mechanical vehicles did not rest with the Ministry that so much difficulty was experienced in correlating the programme for vehicle supply with the programme for the manufacture of spares.[2] The elaborate system of calculations which was introduced when the Ministry became responsible for estimating the wastage of guns included a method of determining the percentage of casualties which would be repairable and the proportion of casualties which would occur to the various parts of the gun or its equipment. The methods used in computing these percentages are described in detail in Appendix II. Here again, as the position in regard to machining capacity, labour and materials became more stringent, the programmes for manufacture and repair needed careful correlation in order that the best use might be made of the resources available.

IV. Stocks.

The reserves which were held at the outbreak of war were just sufficient for the purpose for which they were intended, viz.: to provide a small margin of equipment for the British Expeditionary

[1] Vol. XII, Part IV, Chap. IV. [2] *Ibid.*

Force. The artillery reserve had been fixed as fifteen 18-pdr. batteries, three 13-pdr. batteries and one 60-pdr. battery, while the stock of ammunition had been prescribed by the Mowatt Committee, 75 per cent. being held as empty components.[1] A few weeks' stock of high explosive was held at the Ordnance Factory on behalf of the Navy alone.[2] The serviceable rifles available at the outbreak of war were enough to arm the Forces as they then were, i.e., 620,000 regulars, reserves and territorials, and to leave a balance of 175,000 rifles; but these were not all of the newest pattern.[3] Stocks of small arms ammunition were low; out of a pre-war production of 108,306,000 rounds yearly, the reserve in August, 1914 was only 29,000,000 rounds.[4] No reserves existed of several important classes of novel munitions, such as aircraft and the light types of machine gun, which were still in an experimental stage.

The policy of relying upon contractors to provide their own materials had prevented the holding of any reserve of these beyond what was needed by the Ordnance Factories. The Navy's retention of a certain stock of oleum for cordite manufacture was an entirely exceptional measure.[5] Similarly, no adequate stocks of manufacturing equipment existed, since the expansion of production which called for vast quantities of drawings, specifications and gauges was quite unexpected.

The position improved from the summer of 1916 onwards. When once the new armies had reached their full growth it was possible to build up reserves of rifles and small arms ammunition.[6] As the new capacity for producing gun ammunition came into action during 1916 it became possible to do more than feed the armies from hand to mouth. The output had been arranged by the Minister on a scale in excess of the military requirements with the express intention of accumulating a stock of ammunition as soon as possible. Expenditure of most natures exceeded the rate of issue during the battle of the Somme and the reserves were accordingly depleted; but by the end of the year large stocks of certain heavy natures and of 18-pdr. H.E. shell had again been accumulated. The enormously increased 1917 programme, which threatened to strain the whole resources of the country, gave new importance to the question of reserve stocks, and it became desirable to determine the minimum stock of each store which should be held against emergency.[7]

The quantity of stocks to be held necessarily depended upon the general war policy and the duration of the war, so far as this could be estimated. It was also seriously affected by the amount of storage capacity that was available both at home and in the theatres of war. The storage of filled shell was too hazardous to be undertaken in unnecessarily large quantities. Hence, from 1917 onwards, the manufacturing programme was so arranged as to provide for the accumulation of empty stocks during the winter, while filling was carried on at increased rates during the battle period.[8] The locking

[1] Hist. Rec./H/170/6.
[2] Vol. X, Part IV, p. 38.
[3] *Ibid.*, Chap. I.
[4] Vol. XI, Part VI, p. 15.
[5] Vol. VII, Part IV, p. 38.
[6] *See* above, pp. 30–31.
[7] A.C. 2.
[8] Vol. X, Part V, p. 73.

up of money and material in enormous stocks of empty munitions had obvious disadvantages and tended towards undesirable rigidity; but the alternative of establishing fresh reserves of manufacturing capacity in case of unexpected emergency had even greater disadvantages under the stringent conditions of this time.[1] The programmes for 1918 were very carefully revised so that reserves to be carried over for the 1919 battle period should equal those available for the previous year. This was regarded as the minimum of prudent insurance for the future. It resulted that the stocks in hand at the end of the war were very large.

V. The Problem of Elasticity.

(a) FLUCTUATIONS IN THE DEMAND.

The element of change was the one constant factor in the programme of demand. Even the more stable programmes for standard munitions, which were capable of being formulated for months ahead, were at times gravely affected by lesser alterations. Thus, for instance, the gun ammunition programme for 1917, put forward in October 1916, and settled in January 1917, was modified twice in the following February and again in the following May.[2] In this instance, the chief effect of the modifications was to reduce by considerable quantities the demand for the heavier natures of shell. These drastic reductions involved the dismantling of machinery and the dispersal of labour, and it was expected that it might be impossible to meet any later revival in the demand. In the event, the conversion of heavy shell plant to other occupations, such as aircraft manufacture and gun repair, was accompanied by a permanent loss of a certain small proportion of the productive capacity for shell manufacture.

Fluctuations in the demand for the more novel types of munition, such as trench warfare stores, were apt to be even more violent than those for standard munitions, and in face of these constant changes the supply authority experienced great difficulty in maintaining continuity of production.[3]

(b) STANDARDISATION.

Changes in the nature of the munitions demanded had an even more serious effect upon the business of supply. Under modern methods, whereby bulk output at very rapid rates is attained chiefly by repetition work in large factories, it was extremely disadvantageous to change the pattern of the article to be made, or to make articles of many various patterns. Even where these changes did not involve any considerable alterations to machinery, as for instance in those filling factories where much of the work was necessarily done by hand, the consequent alterations in routine seriously retarded output while workers were being trained to undertake new operations. This difficulty was enhanced during the war by the general lack of experience among the large numbers of operatives who were absorbed into the work of munitions manufacture.

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[1] *See* above, p. 14. [2] Vol. X, Part II, p. 21. [3] Vol. XI, Part I, p. 3.

Constant change in the nature of the demand was an essential feature of some programmes. Chemical warfare supplies, for instance, depended for their success upon the element of surprise. It was continually necessary to introduce new chemical mixtures for which the enemy should be unprepared and to adopt new methods of using them, or to provide new means of defence against the enemy's devices. There was accordingly a peculiar difficulty in correlating the arrangements for supply with the constantly shifting demand. The installation of chemical plant is a very lengthy operation, even when the process for which it is intended is well known and the layout easy to plan. In many instances it became necessary to erect plant on a manufacturing scale for processes which had not yet passed beyond the experimental stages in the laboratory. It happened, in at least one case, that the plans for manufacture were entirely changed because research had shown a quicker method of production. It happened more than once that costly plant, erected at the expense of much time, energy and money, had scarcely begun to produce when a change in military conditions rendered it useless.

(c) Methods of securing Elasticity in Production.

The normal method of providing for expansions in munition production at the Ordnance Factories was to maintain a nucleus of labour with a large proportion of plant. Upon the increased demands arising from the war the number of operatives was brought up to complete the establishment, and throughout 1914 and 1915 almost continuous overtime and week-end labour were maintained. Similar methods were of almost universal application. Night shifts were increasingly adopted throughout the winter of 1915–1916, so that factories might work without a break. At the same time it was considered desirable to reduce overtime as a means of checking industrial fatigue, and of maintaining the maximum output over a long period of time ; but the treble shift system, which was advocated by the Ministry as the best means of getting the largest possible number of machine hours, was not generally acceptable either to employers or to work-people.[1] The increased use of machinery also served to expand output. The enormous factories built for shell manufacture in 1915–1916 were laid out to make the most possible use of repetition work, so that the need for skilled labour should be reduced to a minimum. By centralising work in large units it was also intended to minimise the difficulties of supervision.

The first vast expansion in the munitions programme was met by these means, and by bringing the industrial workshops of the country into the manufacture of warlike material. The general contraction of supply, as a result of the limitations in the programme, which arose from restrictions in tonnage towards the end of the war, presented a problem of almost equal difficulty. The abandonment of the original reliance upon overtime to increase output augmented this difficulty. It was essential to keep together a very considerable proportion of

[1] Vol. V, Part III, pp. 96, 122–124.

the labour at the large factories, in case of a revival of the need for maximum output. For this reason, for instance, it was considered preferable to maintain night shifts in the National Projectile Factories, even though the day shifts would have sufficed for the heavy shell programme of 1917.[1] The shell filling factories, where machinery was not much used, turned over with comparative ease to the work of naval mine filling, aerial bomb filling and breaking down of salved or rejected stores, and by eliminating night shifts and Sunday work from those filling factories which were not engaged upon continuous processes the filling capacity was maintained ready for expansion in case of need.[2] In the great engineering factories, where repetition work was almost universal, it was extremely difficult to make full use of highly specialised plant for other purposes. It was, for example, only by storing vast quantities of idle machinery that the Cathcart National Projectile Factory could be converted to aircraft manufacture.[3]

Apart from the practical difficulties of organising changes in the amount or nature of output, there was always a risk of very considerable financial loss, as the result of altering or reducing contractual obligations. To minimise this risk the running contracts which were placed by the Ministry were terminable upon an agreed notice, ranging from fourteen days upwards according to the nature of the munition and the time taken in producing it.[4] Constant changes in design were a fruitful source of claims for compensation, and at times became so irksome to manufacturers that they were with difficulty persuaded to continue production.[5]

As the war progressed, the increased strain upon the country's resources for munitions supply made the retention of any elasticity in the programme more and more difficult. The enormous capacity for producing certain classes of gun ammunition, which had been created to meet the requirements of the earlier stages of the war, was in itself a new source of rigidity. The new national factories which had then been established were intended for bulk output on a very large scale. In this respect they differed from the older Ordnance Factories, which were expressly organised for constant change. The capacity of the Ordnance Factories was ultimately devoted almost entirely to the production of comparatively small and urgent requirements, and became one of the most important means of meeting sudden demands.[6]

When the programme of demand was formulated sufficiently early, there was comparative ease in securing continuity of production by spreading orders over a longer period of time. Thus shell manufacture could be continued during the winter months, and stocks accumulated towards the battle period. It was only where an accumulation of stocks was undesirable, as in the case of chemical substances and filled shell, that seasonal variations were accepted as unavoidable.[7]

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[1] Vol. X, Part III, Chap. III.
[2] Vol. X, Part V, p. 44.
[3] Vol. X, Part III, Chap. III.
[4] Vol. III, Part II, p. 112.
[5] A case in point is that of the 3-in. Stokes bomb (T.W./Contract/894).
[6] Vol. VIII, Part I, Chap. I.
[7] *See* above, p. 29.

At the end of the war the pooling of the Allied resources in a general munitions programme went far towards stabilising production. It was then possible to make a systematic use of the surplus capacity for guns and gun ammunition, which remained from the reduction in the British programmes, on behalf of the Allies, and to draw from other countries supplies to meet new and increasing requirements, such as those for aero-engines.[1]

VI. Conclusion.

Administrative success depends normally upon a full knowledge of all the conditions affecting achievement, and upon a sound plan for making the best use of them ; for without such knowledge and in the absence of such a plan the administrator's house is built upon a shifting foundation of sand.

During the first uncertain twelvemonth of war the military demand for munitions grew rapidly in all directions. The formation of new armies, totally unexpected increases in the rates of munitions expenditure, entirely unanticipated developments in the kind of weapons required—all contributed to raise the demand beyond any former expectation. While continual growth was apparent, there was no experience upon which to judge either of the rate or the duration of that growth. The normal methods of calculating the establishment of a fixed army and allowing for the replenishment of its consumable stores during the interval between actions failed utterly under these unexpected conditions.

The means of calculating the rate of production broke down just as completely. The extension of subcontracting, large foreign purchases, the spreading of contracts among the general trade of the country, and the establishment of group manufacture, each in turn, and all in the aggregate, contributed to falsify any forecasts of deliveries. Neither the contracts officer nor the Chief Superintendent of Ordnance Factories was in any position to judge of the value of promises made by firms entirely unaccustomed to the exactitude of munition work. Nor were the non-expert firms themselves in any position to estimate the influence of shifting circumstances on their new and ambitious programmes of supply. No one had the requisite knowledge of the full effects which the distribution of manufacture over the whole country was likely to have upon the time occupied by all the diverse operations of supply, from the working out of the pattern and provision of the raw material, through all the processes of manufacture and transport from place to place and the various stages of inspection, to the final issue overseas. There was no experience upon which to judge what time would be occupied in converting the commercial workshops of the nation into a series of munitions factories ; nor was it possible to calculate beforehand how long it would take to train the unskilled and the amateur as an operative.

It was under these circumstances that the Ministry of Munitions undertook in the summer of 1915 to organise the whole of the country's resources for the supply of warlike stores. It was at once found

[1] *See* above, p. 18.

necessary to provide a central authority (the Department of Munitions Requirements and Statistics) to receive and distribute to the various supply departments of the Ministry the various demands received from the War Office, and to return to the War Office their estimates of probable output. But the main feature of the Ministry's organisation at this time was the large measure of branch autocracy which it encouraged, so that, while each supply officer had his own plan of action, there was no attempt to correlate the different plans nor to formulate one comprehensive programme for the whole business of supply. The most complete of the individual manufacturing programmes were those for shell manufacture; but it was not until the spring of 1916 that a comprehensive programme of action was formulated for the whole of the various stages in the supply of complete rounds of ammunition. This individualistic method was peculiarly suited for the period during which the country's manufacturing capacity was being created or organised. As soon as the new factories were in full swing and deliveries were flowing regularly, a more systematic plan of action became both more practicable and more necessary. The effects of a war of attrition began to be felt towards the end of 1916. The problem of man-power then began to concern not only skilled, but unskilled, labour. The general shortage of materials then began to make itself felt. The limits of the nation's credit then began to come into sight. Thenceforward it became the duty of the Ministry to contrive that the resources available should be used to the best effect. All statistical responsibility was concentrated in the Department of Requirements and Statistics, so that the allocation of manufacturing capacity, materials and labour should follow the order of urgency in the requirement, so that the general tendency in each operation in supply might be watched and action taken accordingly, and so that the Ministry's promises of delivery might be based upon a full knowledge of all the factors governing each class of supply. About the same time the Minister's immediate circle of advisers began to consider the programme of supply as a complete whole. The first attempt at a comprehensive programme dates from 1917. The complete method of programme-making had been fully worked out by May, 1918. A later development applied to the whole of the Allied resources the principles already established for supplying the British armies.

The system ultimately adopted consisted in the correlation of two distinct programmes, the one a programme of demand setting out the needs of the Army, and the other a manufacturing programme denoting how far the country's resources would enable the demand to be met. The programme of demand was the concern of the military authority; but it was subject to discussion with supply authorities, and in some exceptional branches, such as chemical warfare, it was entirely dependent upon the possibilities of supply. The manufacturing programme was formulated by the Ministry responsible for supply. The central Department of Requirements and Statistics received the demand and interpreted it for the supply departments. These departments not only made forecasts of the possibility of output in accordance with these

demands, but also set out the quantities of materials, raw or semi-manufactured, which would be needed; calculations which needed highly technical knowledge of manufacturing conditions. It was the duty of D.M.R.S. to ascertain from the officers responsible for materials what proportions of those needed could be obtained. Since, during the period when the system was in force the shortage of materials, and particularly of steel, dominated the whole supply position, D.M.R.S. then scaled down the whole of the manufacturing programme by the amount of steel available. It is indeed probable that under other circumstances the programme would have had to be scaled down by some other limiting factor in supply. It was customary for the effects of every main condition to be reviewed in the general statements, which were prepared by D.M.R.S. and laid before the Minister and his Council for final consideration. Many of the governing conditions lay outside the control of the Ministry. The programme of manufacture had to be brought into accord with conditions more or less predetermined, such as the proportion of tonnage to be allocated to food supply and munitions, the priority to be given to the various means of waging war, or the general policy guiding the use of man-power and money.

The Minister in Council thus adopted the final manufacturing programme with a review of all the relative conditions pictured before him. At different stages consultations took place with the representatives of labour and finance. The manufacturing programme was submitted to the military authorities for final correlation with the demand; and the plan of action was thus at length completed. This, however, was only the first step. The main lesson of the war was that it was necessary to draw up a complete programme at as early a date as possible, in view of all the complexity of supply on a large scale, and because it was essential to realise at once that production occupied certain specific periods of time. For most of the standard munitions it was possible to draw up beforehand a comprehensive programme covering a period of at least six months. Its details were, however, continually subject to modification. It was the duty of the Director of Requirements and Statistics on the one hand to watch these changes and to interpret them for the supply departments, on the other to watch the progress of supply in order to show clearly (*a*) whether the output was following the plan laid down, and (*b*) which activities of the Ministry needed hastening or curbing. It was also his function to lay down the lines upon which statistical information was to be recorded by the different supply departments, so that lack of uniformity might not undermine the whole statistical basis of the programme. The Department of Requirements and Statistics was to provide a means for synchronising the manufacture of various types of munitions, for balancing the production of all the components and operations involved in producing a complex store, and for estimating the proportion of capacity to be utilised for manufacture or repair. It was, in fact, the intelligence department within the management of a great munitions business consisting of all the workshops of the nation. While it had no actual control over action, it had wide powers for recording progress and formulating plans for future action. The

essence of its position was that it should be in close touch on the one hand with the Minister in Council, on the other, through specialised officers, with the various supply branches of the Ministry.

In practice it was also found desirable that the calculations as to wastage and repair should be undertaken by the programme-making authority. At these and at many other points the manufacturing programme was so closely inter-related with the programme of demand, that it was necessary for D.M.R.S. to be in intimate connection with the officers responsible for formulating the military requirement.

In the light of later events it is conceivable that an earlier adoption of the methods, which were thus gradually introduced, might at least have prevented the difficulties which arose from over-sanguine estimates of supply during the earlier months of the war. It is clear that an earlier introduction of a system for correlating the various activities of demand and supply would have been essential had the resources of the country been as restricted in the earlier years of the war as they were in the years 1917 and 1918. The final organisation for programme making is thus highly important, since under other circumstances, for example, with the closing of important overseas markets for materials and complete munitions, it might become necessary at the very outset of a war to set on foot some similar organisation for making the best possible use of every available source of supply.

APPENDICES.

APPENDIX I.

(CHAPTER III, p. 23.)

Procedure in regard to Statistics.[1]

Requisitions.—The Director of Munitions Requirements and Statistics (D.M.R.S.) is responsible both for the receipt and distribution of the requirements of the Army Council and the Allies, and also for the collection and distribution of inter-departmental requisitions, e.g., for raw material.

D.M.R.S. forwards requirements as and when they are received, to the Supply Departments, where the quantities of material needed are calculated. These calculations form the basis of raw material requirements, which go through D.M.R.S. to the Materials and Steel Production Branches, who in conjunction with the Supply Departments report to D.M.R.S. what proportion of the requirements can probably be met.

All forecasts or promises of delivery to the War Office are made through D.M.R.S.

Progress.—D.M.R.S. keeps in touch with the output of the various departments as shown by statistics, and draws attention to deficiencies or excesses. Whenever supply arrangements for minor demands are held up, D.M.R.S. is informed immediately, without waiting for his enquiry.

Priority.—D.M.R.S. compiles and issues, with the Minister's sanction and after consultation with heads of departments, the War Office, Admiralty and Board of Trade, a monthly analysis of munitions arranged in order of urgency. The co-operation of all departments is expected to make this analysis comprehensive enough to guide those responsible for priority decisions in detail or for allocating labour, material, machinery, etc., between various uses.

Statistics.—Each department keeps its detail statistics on as simple a basis as possible, and upon a form that, with due allowance for time lag between operations, can be reproduced as graphs and super-imposed, showing clearly the position of the various items making up the munitions programme. To avoid reduplication it is agreed beforehand which department compiles each set of statistics, obtains the necessary returns and supplies the results to the departments concerned. Each department's statistics include figures showing (where possible) the estimated programme for six months ahead for comparison with actual deliveries.

Each department agrees as soon as possible the working stock of material or partially or wholly manufactured components which should be held in the different stages of manufacture or supply. The agreed figures form the basis of the stock taken into account in statistics presented to D.M.R.S.

Each statistical section supplies D.M.R.S. with the information he requires for compiling the complete statistics of the Ministry. D.M.R.S. generally deals only with the finished statistics of any department, and with their co-ordination into a homogeneous statement showing the actual and prospective position in regard to supplies. D.M.R.S. is provided with copies of all special statistical statements or regular returns.

Statistical Conference.—A conference of the members of the statistical sections is convened weekly by D.M.R.S., in order to co-ordinate all statistics. The conference agrees upon the lines on which statistics are to be compiled, eliminates duplication and compares and agrees the statistics prepared by each section. One member of the staff of D.M.R.S. devotes his whole time to the conference. Two members of the conference prepare, in conjunction with representatives of the Materials Division (including the Steel Production Branch) a comprehensive statistical scheme of materials. Statistics kept by the Materials Division show, as far as possible, the relation between the requirements of the Ministry, the other Government Departments and the Allies, and the total supplies of materials known to be available for the Allies' use.

The conference is composed of Mr. W. T. Layton (D.M.R.S.), chairman; Mr. C. H. Stevens (Assistant Controller of Shell Manufacture), vice-chairman; Mr. M. S. Birkett (of the M.R.S. branch), secretary; Mr. H. A. Fortington, specially concerned with raw material requirements; one other member, and the statistical officers required to attend from time to time.

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[1] An epitome of General Procedure Minute, No. 68 (20 January, 1917; copy in HIST. REC./R/263.021). For subsequent modifications to the procedure so far as programme making was concerned, see above, p. 24.

APPENDIX II.

(CHAPTER IV, p. 27.)

The Calculation of Estimated Wastage for Guns and Carriages.

Returns are obtained for actual casualties to guns and carriages over as long a period as possible, subdivided (1) into casualties due respectively to enemy's shell-fire, premature explosion, and wear; and again (2) into repairable and non-repairable casualties. It is assumed that shell-fire casualities vary in direct proportion to the number of firing points, and that premature casualties and (in the case of carriages) casualties due to wear, vary in proportion both to the number of firing points and to the amount of ammunition expended. In the case of guns, wear casualties are calculated, not directly from the rate obtaining during previous experience, but by dividing the life of the gun (in terms of ammunition rounds) into the amount of ammunition estimated as likely to be expended. It is further assumed that all wear of guns is repairable, and that other wastage will contain repairable and non-repairable casualties in the same proportion as has obtained hitherto, as follows :—

1. From the returns supplied from General Headquarters, France, the average monthly casualties actually reported during a given period (usually the past 12 months) are calculated separately for (1) offensive and defensive periods (usually taken as from 1 March to 30 November and 1 December to 28 February respectively), (2) gun bodies and carriages, (3) each important nature regardless of subdivision into marks, (4) shell-fire, premature and wear (actual wear casualties for guns are needed only for comparison).

2. The average number of guns for each nature actually firing in the field is calculated for the past period offensive and defensive. The estimated number of firing points during future periods is taken as given by the War Office statements of establishment to be maintained with units. Where this establishment will only gradually be attained, appropriate allowance must be made. The ratio of this estimated future establishment to the average actual establishment in the past is then calculated as a percentage.

3. Similarly the actual average monthly expenditure of ammunition is calculated for each nature for the given periods of the past; and the estimated average monthly expenditure during the future is calculated from the War Office requirement. The latter calculation is made either (*a*) by multiplying the number of firing points by the ration (given in terms of rounds per gun per day), or (*b*) by adding to stocks actually available at the beginning of the period the output required during the whole period and subtracting the balance required to be available at the end of that period (usually a six weeks' firing allowance). The figures thus obtained are converted into monthly averages by assuming that an average month comprises $\frac{365}{12}$ days.

4. For guns (*a*) the actual shell-fire casualties (obtained as in paragraph 1) are multiplied by the ratio for the change in establishment (as obtained in paragraph 2), (*b*) the actual premature casualties (obtained as in paragraph 1) are multiplied by the ratio for change and expenditure (as obtained in paragraph 3),[1] (*c*) to estimate wear the estimated monthly expenditure is divided by the gun life expressed in terms of rounds. This life has been from time to time revised on the basis of returns for actual expenditure and actual wear over long periods, and in the light of actual measurements of the state of wear carried out for all guns in the field except the more numerous field guns.

5. These estimates, subdivided according to cause of wastage, are then redivided according to repairability of wastage. The total number of actual shell-fire and premature casualties to guns is obtained for as long a period as possible, regardless of division into offensive and defensive phases. For approximately the same period (allowing, that is, a month's delay for transport and sentencing) the total number of actual non-repairable gun casualties is obtained. The latter figure is then expressed as a percentage of the former for each nature separately.

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[1] It should be noted that algebraically this single ratio allows for change both in establishment and in ration.

6. This percentage, showing the proportion of non-repairable casualties contained in actual shell-fire and premature, is then applied to the estimated monthly casualties for shell-fire and premature combined. The resultant figures furnish the average monthly estimates of non-repairable casualties. Since for guns all wear casualties are assumed to be repairable, the total estimates for repairable wastage are found by subtracting the estimated non-repairable casualties from the grand total embracing alike shell-fire, premature, and wear.

7. For carriages, the estimates for shell-fire were formerly obtained by multiplying the actual averages for shell-fire by the ratio for the change in establishment, and the estimates for premature and wear by multiplying the actual figures for these casualties by the ratio for change in expenditure. In practice, however, it is found that estimates of equal, if not superior, accuracy are obtained by multiplying the actual figures for casualties of all kinds simply by the ratio for change in establishment.

8. The percentages of non-repairable casualties contained in the totals for all forms of carriage wastage (including wear) is found much as for guns.

9. By means of these percentages the estimated averages for non-repairable casualties are found for carriages, the balance out of the estimated total being taken as repairable.

10. The basis of these casualties has always been taken from returns of actual wastage in France only. Accordingly, where it is desired to include in the estimates figures for other theatres in addition to those for France, an appropriate percentage is added. Originally, an arbitrary figure of 12·5 per cent. was added and regarded as providing a margin to cover unforeseen contingencies generally. For the beginning of the offensive period 1918 an additional insurance of this kind was made. As it was supposed that German counter-battery work would be far more efficient than in the past, the estimates for shell-firing casualties, obtained as above, were doubled throughout. Both these allowances, however, were found to be far too high. It is now deemed sufficiently generous to assume that the rate of casualties obtaining in other theatres will be the same as in France, and merely to add to the estimates for France a percentage equivalent to the ratio of the establishment maintained in other theatres to that maintained in France. No estimates are made for guns captured by the enemy. Such losses it is assumed will be covered by the Battle Reserve.

11. In actual fact there is no sudden increase of wastage in passing from the defensive to the offensive periods, and no sudden drop on reverting to the defensive. The flat rates given by the average monthly estimates, calculated as above for the offensive and defensive periods respectively, are accordingly graded empirically to give a smooth curve with a maximum about July and a minimum in January. It is assumed that the transport and repair of guns and carriages occupies approximately four months. The capacity for repair is limited by manufacturing plant available; and where the estimate thus inferred would exceed the capacity, the balance is held over until a subsequent month. The difference, positive or negative, between the total estimates for casualties, repairable and non-repairable, and the total estimates for output, new and repaired, shows the net change in the number of guns available during that month. Accordingly, starting with the stock in hand at the present date, and adding or subtracting successively the net changes during each future month, it is possible to estimate the number of guns available at the end of every month throughout the period contemplated.

APPENDIX III.

(CHAPTER V, p. 37.)

Comparison of Shell Output in March and June, 1916 and 1917, with Programme.

NATURE.	OCTOBER, 1915, PROGRAMME.						NOVEMBER, 1916, PROGRAMME.					
	March, 1916.			June, 1916.			March, 1917.			June, 1917.		
	Weekly Require-ments, Oct., 1915, Programme	Modified Weekly Require-ments, Mar., 1916.	Average Weekly Filling, Mar., 1916.	Weekly Require-ments, Oct., 1915, Programme.	Modified Weekly Require-ments, June, 1916.	Average Weekly Filling, June, 1916.	Weekly Require-ments, Nov., 1916, Programme	Modified Weekly Require-ments, Mar., 1917.	Average Weekly Filling, Mar., 1917.	Weekly Require-ments, Nov., 1916, Programme	Modified Weekly Require-ments, June, 1917.	Average Weekly Filling, June, 1917
18-pdr. H.E. ..	350,100	233,400	105,116	402,600	700,000	250,754	600,000	600,000	542,662	600,000	470,000	494,479
,, S. ..	350,100	233,400	152,884	402,600		316,422	600,000	600,000	471,000	600,000	600,000	385,448
4·5-in. How. H.E.	202,500	—	66,109	262,010	179,670	128,001	292,500	279,750	294,182	292,500	280,000	259,378
,, ,, S.	7,500	—	4,627	7,500	8,500	8,325	21,500	—	—	21,500	4,000	2,230
60-pdr. H.E. ..	30,800	23,100	7,355	52,270	30,380	20,701	48,000	33,750	42,094	51,000	65,500	61,594
,, S. ..	30,800	23,100	2,962	52,270	30,380	11,753	60,000	45,000	38,391	63,000	63,500	58,589
6-in. How. H.E. ..	52,270	40,210	9,696	93,330	36,400	43,123	200,000	225,000	154,898	245,000	200,000	219,202
6-in. Gun H.E. ..	1,350			1,350	1,350		6,000	4,000	5,223	7,500	6,100	5,398
,, ,, S. ..	1,350	1,010	805	1,350	1,350	393	6,000	4,000	4,299	7,500	6,500	5,779
8-in. How. H.E. ..	14,930	11,200	3,719	27,070	9,240	7,904	65,000	65,000	50,420	86,000	45,000	31,864
9·2-in. How. H.E.	8,400	6,300	2,714	15,870	9,240	8,949	58,000	37,500	37,994	62,000	30,000	30,672
9·2-in. Gun H.E...	140	100	—	140	100	57	100	100	283	150	150	277
2-in. How. H.E...	3,270	2,450	375	3,590	1,960	1,069	4,250	—	578	5,000	2,000	2,431
15-in. How. H.E...	560	420	65	560	420	203	510	150	129	510	200	194

APPENDIX IV.

(Chapter V, p. 38.)

Deliveries, Stocks, Issues and Expenditure of Certain Types of Shell, Yearly (1916—1918).[1]

Year.	Empty Deliveries.	Empty Stock.[2]	Filling.	Issues.[3]	Filled Stock.[4]	Expenditure
			18-Pdr. H.E.			
1916	22,960	12,872	11,873	11,860	7,097	8,360
1917	14,701	5,192	20,609	20,614	15,077	15,637
1918	14,715	5,084	14,318	14,490	10,945	14,213
			18-Pdr. Shrapnel.			
1916	22,633	4,680	22,519	21,003	Included in H.E.	15,276
1917	26,222	3,537	27,445	27,378		22,449
1918	22,804	6,121	18,423	18,497		19,763
			4·5 in. Howitzer.			
1916	11,775	2,805	8,262	7,662	1,471	4,815
1917	13,697	2,286	13,951	13,028	2,662	10,664
1918	13,193	4,626	10,564	8,931	3,283	9,467
			9·2 in. Howitzer.			
1916	1,265	202	961	789	306	549
1917	2,765	1,137	1,723	1,752	445	1,547
1918	1,039	850	1,062	1,135	436	950

[1] All figures are in thousands.
[2] Empty stock figures denote the stock held at the end of each year.
[3] Figures denote issues to the War Office, not overseas.
[4] Filled stock figures denote the stock held at the end of 1916 and 1917, and on 17 November, 1918.

APPENDIX V.

(CHAPTER V, p. 40.)

Table showing the relative Cost and Quantities of Steel, Labour and Imports required for the 1918 Programme.

	Actual Figures (in Thousands).				Percentage Figures.			
	Steel.[1]	Imports.	Cost.	Labour.	Steel.[1]	Imports.	Cost.	Labour.
	Tons.	*Tons.*	£	*Nos.*	*Tons.*	*Tons.*	£	*Nos.*
Admiralty	165·0	—	30,000	900	36·5	—	35·0	36·4
War Office	45·0	—	—	550	10·0	—	—	22·2
Raw Materials	—	—	14,000	—	—	—	16·4	—
Trench Warfare Supplies	17·8	4·3	2,500	—	3·9	6·8	2·9	—
Railway Materials ..	40·0	6·3	900	—	8·8	10·0	1·1	—
Tanks	8·0	11·0	1,100	30	1·75	1·7	1·3	1·2
Mechanical Transport ..	4·8	11·0	2,200	80	1·05	1·7	2·6	3·2
Aeroplanes	11·0	17·0	8,700	225	2·4	2·7	10·4	9·2
Ordnance	24·0	40·0	2,300	140	5·3	6·3	2·7	5·6
Small Arms and S.A.A.	6·7	18·5	1,400		1·5	2·9	1·6	
Ammunition	130·0	430·0	22,000	550[2]	28·8	67·9	26·0	22·2[2]
Total ..	452·3	538·1	85,100	2,475	100·0	100·0	100·0	100·0

[1] Home manufacture only: shell steel from abroad amounted to 50,000 tons.
[2] Includes trench warfare ammunition.

APPENDIX VI.

(CHAPTER V, p. 42.)

The Balancing of Components: Week Ending 5 February, 1916.

(a) SUPPLY OF METAL COMPONENTS.[1]

	Shell.		Cartridge Cases.		Primers or Tubes.			Fuses or Gaines.		
	Delivered during Week.	Stock at end of Week.	Delivered during Week.	Stock at end of Week.		Delivered during Week.	Stock at end of Week.		Delivered during Week.	Stock at end of Week.
Shell using Primers[3]	950,998	7,042,865	941,158	2,843,025	Primers	1,396,373	2,444,776	H.E. Fuses[6] ..	264,105	1,864,555
Shell using V.S.P. Tubes[4]	3,763	14,798			V.S.P. Tubes	5,000	—	Shrapnel Fuses[7]	270,607	222,955
Shell using Friction Tubes[5]	41,209	123,974			Friction Tubes ..	201,450	308,606	Gaines	390,559	1,048,552
Total Shell	995,970	7,181,637								

(b) FILLING.[2]

	Shell.		Cartridges.		Primers or Tubes.			Fuses or Gaines.		
	Filled during Week.	Stock at end of Week.	Filled during Week.	Stock at end of Week.		Filled during Week.	Stock at end of Week.		Filled during Week.	Stock at end of Week.
Shell using Primers	297,536	1,045,560	457,504	856,589	Primers	425,197	1,907,584	H.E. Fuses ..	166,550	348,511
Shell using V.S.P. Tubes	8,073	6,523	3,652	4,535	V.S.P. Tubes	5,000	31,700	Shrapnel Fuses	252,267	669,322
Shell using Friction Tubes	19,538	164,874	36,699	68,084	Friction Tubes ..	53,218	150,755	Gaines	133,200	22,020
Total Shell and Cartridges	325,147	1,216,957	497,855	929,208						

[1] The delivery figures include shell and components delivered filled both from Home and Abroad: the stock figures relate to empty stores only.
[2] The figures include filled shell and components from Abroad. [3] i.e., 18-pdr. H.E. and S.; 13-pdr. H.E. and S.; 4·5-in. H.E. and S. [4] i.e., 4·7-in. H.E. and S.; 6-in. Gun H.E. and S.
[5] i.e., 10-pdr. H.E. and S.; 2·75-in. H.E. and S.; 60-pdr. H.E. and S.; 6-in. Howitzer H.E.; 8-in. Howitzer H.E.; 9·2-in. H.E.; 12-in. H.E.; 15-in. H.E.
[6] i.e., Fuses Nos. 17, 44, and 100. [7] i.e., Fuses Nos. 65a, 80, 85, 82, 83.

VOLUME IX

REVIEW OF MUNITIONS SUPPLY

PART II

DESIGN AND INSPECTION

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CHAPTER I.

INTRODUCTORY.

I. Administrative Methods for Maintaining Quality.

In time of war men's lives, the *morale* of armies, victory or defeat depend upon the safety and efficiency of the fighting equipment with which the soldier is provided. But the balance between safety and danger, effectiveness and uselessness, is extremely delicate in such complex weapons as the modern rifle, the heavy gun, or the high explosive shell, whose patterns have been gradually developed from a close and scientific study of the action of various forces. Departure from pattern by one-thousandth part of an inch may turn the scale one way or another. The use of a steel containing one-hundredth part too much of sulphur or phosphorus may cause the bursting of a gun or the failure of many rounds of ammunition. Slight but frequent variations in the size of a wooden box may falsify all the calculations for transport in an advance. Even the omission of a single line of paint, which serves to distinguish one class of shell from another, may bring about misuse and consequent disaster.

To the producer, insistence upon such minute points is particularly irksome when their uses are not self-evident and when manufacture is carried out at high pressure. It, therefore, becomes necessary to introduce some regular procedure into the business of supply in order to ensure compliance with essential military conditions. The normal trade method of ordering a standard article to a general description or to a sample is insufficient for the purpose. Every warlike store has its own detailed specification and drawing, showing clearly the minute limits within which variation may be tolerated. It is the duty of the design authority to authorise these drawings and specifications. It is the function of the inspection authority to see that manufacture takes place in accordance with them. No contract is placed without an agreement to work to a specific drawing and specification. No acceptance is taken and no payments are made except upon the inspector's certificate that the stores have reached the required standard. A stringent enforcement of these two principles necessarily ensures the good quality of the munitions issued to the forces. In fine, the maintenance of good quality is an administrative question and concerns the organisation of the work of design and inspection.

II. The Position of Supply, Design and Inspection before the War.

The administrative organisation for design and inspection in 1914 was a legacy from various developments in the methods of supplying both services with warlike stores. Its character can best be understood in the light of departmental changes which had taken place during the previous century.

In the earlier years of the nineteenth century the provision, inspection and storage of "warlike stores" for both services, as well as responsibility for their pattern, was undertaken by the Board of Ordnance; but in 1855 this Board was abolished and all its functions transferred to the Department of the Master-General of the Ordnance, in the War Office, and placed under the Director of Artillery.

In 1868 the Secretary of State for War made proposals to the Admiralty regarding the redistribution of some of these responsibilities, to the effect that the supply and storage of all warlike stores for the naval service should be provided for in the naval estimates. The objection made to this was that it would necessitate the formation of a new Department of Naval Ordnance, which would lead to difficulty and confusion. The discussion was continued without definite result until, in 1880, the necessity for the provision of special turret mountings for certain naval guns rendered some development inevitable. The Admiralty accepted the responsibility for the supply, and with it for the inspection of these stores.

The consideration of the unsatisfactory nature of the division of the responsibility for supplies between the two services occupied the attention of the War Office and the Admiralty for some years longer. Conferences between the War Office, the Admiralty and the Treasury were held, the balance of opinion being apparently in favour of a further responsibility being placed on the Admiralty, without any definite decision as to the time or principles of transfer. A solution of the difficulties was offered in May 1887 in a letter from the Admiralty to the Treasury, in which it was stated that after review of the difficulties involved, and very careful deliberation,

> "My Lords are decidedly of opinion that the best, if not the only solution, of the difficult problem is to establish an independent ordnance department, common to both Army and Navy, which should be responsible for the efficient supply of all war material for both services. It would in their opinion be essential that the department should be entirely independent both of the Admiralty and the War Office, and it is therefore necessary that it should be placed under a separate and independent Parliamentary head.'

Suggestion was further made for the association of the Director of Naval Ordnance and the Director of Artillery with the head of the Ordnance Department, in order that the latter might be kept in touch with the requirements of the respective departments, and with the requisitions for stores approved of by the Admiralty and the War Office.

The readjustment of the responsibilities of the two great Departments of State was the subject of much further discussion, until, in 1891, a separate Naval Ordnance Department was formed. The duty of supplying its own warlike stores was thus allocated to each of the two services. This differentiation endured throughout the war, for the Ministry of Munitions, which was established in 1915, was responsible only for satisfying the requirements of the Army, and (later) those of the Air Forces. Both the Army and the Navy drew continuously upon the output of the Ordnance Factories and shared the facilities for

research and the advice of technical experts at Woolwich. At the same time, responsibility for the design of munitions was taken by the Director of Naval Ordnance in the case of naval stores; by the Master-General of the Ordnance and (later) by the Director-General of Munitions Design of the Ministry of Munitions in the case of land service stores.[1] For a time, after the establishment of the Department of Naval Ordnance, the duty of inspecting naval and land service stores remained first with the Ordnance Factories and later, with the distinct Inspection Department, which was set up in 1888 as a part of the War Department. In 1908, a distinct Naval Inspection Department was formed, special provision being made to secure interchangeability of inspection duties between naval and military inspectors.[2] During the war, the duty of inspecting naval stores was retained by the Admiralty, while the Ministry of Munitions ultimately set up its own organisation for inspecting the land service stores which it supplied.[3]

The chapters which follow deal only with the development of administrative organisation for the design and inspection of those stores which it ultimately became the duty of the Ministry of Munitions to supply.

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[1] See below, Chapters II, IV. [2] See below, p. 8.
[3] See below, Chapter III.

CHAPTER II.

THE MACHINERY FOR DESIGN AND INSPECTION IN 1914.

I. The Responsibilities of the Master-General of the Ordnance.

At the outbreak of war, responsibility for the kind and the quality, as well as the quantity, of a great part of the Army's equipment rested with the Master-General of the Ordnance. It was his function to hold the balance between the needs of the soldier, the development of science and the practical conditions of manufacture.[1] He was responsible for the pattern, provision and inspection of guns, small arms, ammunition, Royal Artillery and Royal Engineer technical stores, and of the vehicles for transporting them. He administered the manufacturing departments (except those engaged upon clothing) and controlled the technical staff engaged upon manufacture, inspection and instruction. He was also responsible for the treatment of patents and inventions. His department was divided into two distinct directorates, the one concerned with artillery and artillery material under a Director of Artillery; the other with the Royal Engineers and their equipment, under the Director of Fortifications and Works. The Directorate of Artillery was divided into three sub-divisions corresponding to certain classes of stores, viz. :—fixed armament, field armament and small arms with vehicles. Each sub-division was responsible for the pattern and inspection of its own stores and for carrying out experiments, in addition to its duties in regard to the provision and allotment of such stores. A fourth sub-division (A.) 4 was responsible for the administration of certain technical and manufacturing establishments, whose work related in a greater or less degree to research and experiment. These included the Ordnance Board, the Royal Artillery Committee, the Research Department, Woolwich, the Experimental Establishments at Woolwich and Shoeburyness as well as the Inspection Department and the Ordnance Factories. This sub-division was also responsible for the receipt of inventors' suggestions and their circulation to the proper authority.[2]

II. The Machinery for Design.

For all important matters the main technical adviser to both the Director of Artillery and the Director of Naval Ordnance with regard to munitions was the Ordnance Board, who had available as consultants the Chief Superintendent of Ordnance Factories in regard to manufacturing questions, the Superintendent of Research in regard to ballistic and chemical questions, the Superintendent of Experiments,

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[1] 1/Genl. Nos./1608.
[2] *War Office Administrative Directory*, 1914.

Shoeburyness for trials of gun equipments, range and accuracy series, and the Chief Inspector, Woolwich as to the effect of service conditions, inspection and cognate matters. The Board consisted of a number of technical experts, both naval and military, and its control over matters of design for both services had been greatly strengthened since its formation from the Ordnance Committee and Ordnance Research Board in 1907. Prior to the war the Royal Artillery Committee also acted in a similar, advisory, capacity towards the Director of Artillery in regard to field gun equipments and range finding stores, and referred to the same consultants, but more particularly to the Chief Superintendent of Ordnance Factories and the Chief Inspector, Woolwich.

In the Directorate of Artillery, it was firmly maintained that no officer should judge of the serviceability of any pattern or modification to a pattern which he had himself created.

Accordingly, the initiation of design for such stores was left to contractors, to the Ordnance Factories, to the Research Department, Woolwich, or to the private individual; while the officers of the directorate passed sentence upon the designs submitted in the light of their own military experience and of the general policy as to equipment.

The Research Department, Woolwich, was equipped for investigating a large range of subjects which might be referred to it either by naval or military authorities. Previous to the formation of this department in 1903, the War Department Chemist, Woolwich, had carried out research and experiment for both services, especially in regard to explosives. With developments in the use of smokeless powder and with the introduction of high explosive charges for shell, existing facilities proved inadequate for this purpose. A research committee on explosives was appointed in 1901, under the chairmanship of Lord Rayleigh and was converted into a permanent research department in 1903, having its experimental buildings and laboratories on the edge of the Plumstead Marshes adjacent to the Proof Butts. In order to facilitate experiment in respect to ballistics these Butts were included within the Research Department, instead of being controlled by the Inspection Department. Experimental stores were made for the Ordnance Board by the Ordnance Factories and examined by the Research Department. The recommendations made by the Ordnance Board were based upon trials, which the Superintendent of Experiments carried out at Shoeburyness, or upon the results of tests at the Proof Butts, Woolwich. Procedure in regard to the design of small arms was somewhat different. The duties of the Small Arms Branch of the Directorate of Artillery included the development of patterns as well as the final sentencing of the design. The branch directly controlled experimental work. Reports on the experimental rifles manufactured at Enfield were made by the Chief Inspector of Small Arms and trials were executed by the experimental officer at the School of Musketry, Hythe, at the instance of the Small Arms Committee, an advisory committee attached to the Small Arms Branch.

No service store could be manufactured until sealed drawings had been provided of the store itself and of the necessary gauges. The

drawing offices of the Ordnance Factories prepared the drawing of the store, or it was forwarded by the individual firms or designers. The drawing of the gauge was the work of the Inspection Department, which also drew up the specification. Upon receiving the final sanction of the Director of Artillery, the Inspection Department sealed the drawings and printed copies for issue to contractors. The Ordnance Board, Research Department and Inspection Department were located at Woolwich in close proximity to the Ordnance Factories. Hence, there was every facility for close co-operation between the various officials who were concerned in the development of a design. Procedure in regard to the pattern of engineering stores was less complex, since the Directorate of Fortification and Works had its own drawing offices at headquarters.

Efficiency and safety were the first concern of these design authorities. Investigations progressed slowly from point to point, in order that results might be based on a sound system of trial and error. In time of peace the need for economy strictly limited the scope of experiments and restricted changes in the nature of the Army's equipment. The position was entirely changed by the outbreak of hostilities. After some experience of European war, it was written of gun ammunition that

> " the business of producing ammunition which shall be safe to transport, handle and fire, but as deadly as possible............ is essentially one of a highly empirical nature..........It is a science, progress in which is necessarily slow in peace, but which starts into frenzied activity under the impulse of war and progresses from experimental design to experimental design in a manner wholly and entirely inimical to the interests of economical production."[1]

The same facts applied to the design of practically every article in the armament and fighting equipment of the forces.

III. The Organisation for Inspection, July, 1914.[2]

(a) DISTRIBUTION OF DUTIES.

While the quality of the soldier's personal equipment was tested by officers within the Directorate of the Quartermaster General responsibility for the inspection of his fighting equipment rested with the Master-General of the Ordnance, and under him, the Chief Inspector, Woolwich, carried out the inspection of all kinds of artillery *matériel*, The Chief Inspector of Small Arms dealt with rifles, machine guns, swords, lances and cycles, and the Inspector of Royal Engineer Stores inspected instruments, telephones and telegraphic apparatus and similar articles.

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[1] C.R./Filling/347.

[2] Based upon a more detailed account of the Department in July, 1914, compiled by Colonel J. R. Stansfeld, C.B., C.B.E., then Chief Inspector, Woolwich (HIST. REC./H./900/19 pp. 14–71).

Until 1888 inspection for both services had been undertaken by the Ordnance Factories. The duties of inspection were then first organised in a self-contained department under the War Office as a result of recommendations by Lord Morley's committee. This committee had been appointed in June, 1886, "to inquire into the Organisation and Administration of the Manufacturing Departments of the Army," one of the causes for its appointment being the failure of certain weapons during the recent Egyptian campaign. After taking very voluminous evidence and sitting for more than a year, the committee submitted a long report in July, 1887, recommending *inter alia* the separation of inspection from the control of the Ordnance Factories, and that it should be placed in the hands of an "Inspector General of Warlike Stores" who was to be an official of the War Office, ranking with, but independent of the Director of Artillery, but like him responsible to the same head. The committee recommended that "all weapons of war, and stores supplied to the Army should be tested and passed under his direction and on his responsibility." This recommendation was approved so far as concerned the removal of inspection from the Ordnance Factories but not as regards the appointment of an independent official at the War Office solely responsible for its efficiency. Instead of the latter, the various sections into which it was decided to divide inspection (each under a Chief Inspector) were placed immediately under the control of either the Director of Artillery or the Director of Equipment and Ordnance Stores, to the former being apportioned those sections which dealt with fighting equipment, whilst the latter had those concerned with what may be termed the personal equipment of the Army.

The Inspection Department thus determined on was formed in the following year, 1888, and consisted of three sections under the Director of Artillery, namely, those of the Chief Inspector, Woolwich, the Chief Inspector of Small Arms, and the Chief Inspector of Range Finders, and two sections under the Director of Equipment and Ordnance Stores, namely, those of the Chief Inspector of General Stores, and the Chief Inspector of Army Clothing. In addition to these was a smaller section, that of the Inspector of Royal Engineer Stores, which was under the Director of Fortifications and Works, and thus was attached to the Department of the Master-General of the Ordnance.

Particular attention continued to be directed towards the needs of the Navy in regard to inspection and experimental work in the event of a war in which both land and sea forces were engaged, and in 1906 an inter-War Office and Admiralty Committee, under the presidency of Admiral Sir John Fisher, considered the question of what remedies or alterations in the existing system would be necessary to meet those needs, "having in view the importance of maintaining the fighting efficiency of the fleet and its instant readiness for war."

The committee's recommendations all tended towards decentralisation, elasticity, and interchangeability of inspection duties where possible, as in the case of raw material, by officers serving the War Office and Admiralty; they included an extension of the system

of inspection and proof of guns at contractors' works, in particular by naval officers, and the formation of a separate Naval Inspection Department.

The recommendations were approved, and with a view to the provision of staff for the proposed new department, a number of naval officers were attached for training to the staff of the Chief Inspector, Woolwich, some at Woolwich and some at Sheffield. In January, 1908, the Naval Inspection Department was actually formed, by the appointment of a Chief Inspector of Naval Ordnance at the Admiralty and the transfer three months later to his control (from that of the Chief Inspector, Woolwich) of the Inspector of Steel at Sheffield with his staff, which latter by that time largely consisted of naval officers, the few remaining army officers being gradually replaced as their terms of service expired by naval officers withdrawn from Woolwich, so that by the beginning of 1912 the staff consisted entirely of naval officers.

At the time of this transfer the Inspector of Steel dealt only with the inspection of raw materials, chiefly steel, and the superintendence of guns manufactured by the armament firms, but steps were at once taken to expand his capacity to deal with naval shell produced in the provinces, except in regard to proof which still remained with the Chief Inspector, Woolwich. Later, a further extension was effected by starting the proof of contract-made naval guns at contractors' ranges. The idea of interchange of duties between the Naval Inspection Department and the Chief Inspector, Woolwich, was given effect to as far as was commensurate with the Inspector of Steel's facilities, and was governed mainly by geographical considerations, the Chief Inspector, Woolwich, dealing with naval stores produced at Woolwich or sent to Woolwich for inspection, whilst the Inspector of Steel dealt with army stores produced in his area, which comprised the Midlands and North of England, and Scotland. Land service guns and shell were, however, all sent to Woolwich for final examination and proof. It may be here observed that the Inspector of Steel had no facilities for dealing with explosives, consequently any work in connection with them was performed by the Chief Inspector, Woolwich, irrespective of locality.

The transfer of the Inspector of Steel, together with that of the Proof Butts previously mentioned, had deprived the Chief Inspector, Woolwich, of two important inspectorates, but the depletion was made up by the addition of the Department of the War Department Chemist, whose work had been appreciably reduced on the formation of the Research Department and the Department of Range Finders Inspection, which had also suffered diminution on the completion of the installation of position finders. The post of Chief Inspector of Range Finders was abolished and merged in that of Chief Inspector, Woolwich.

The Departments of the Chief Inspector, Woolwich, and the Chief Inspector of Small Arms were the only inspection branches which were transferred to the Ministry of Munitions in the summer of 1915, and it is with them alone that this statement is concerned. The work of the Chief Inspector of Small Arms in 1914, was considerably

less than it had been in 1888, by reason of the introduction of the magazine rifle. At the outbreak of war, the main branch of his department was at the Royal Small Arms Factory, Enfield. His small inspection branch at Birmingham had been by this date practically abolished and his staff consisted of three officers and a small number of subordinates.

(b) THE SPECIAL FUNCTIONS OF THE CHIEF INSPECTOR, WOOLWICH.

The Department of the Chief Inspector, Woolwich, was the largest and most important of the inspection branches. It was located in the Royal Arsenal. It dealt with the stores which are now generally styled "munitions," and were formerly termed "warlike stores," namely, guns, carriages, vehicles (other than mechanical transport), ammunition of all kinds with the packages for storage and transport, rangefinding and optical stores, mines, the explosive portions of torpedoes, bombs, grenades and many miscellaneous articles. It had three kinds of function, advisory, informative and administrative.

The advisory functions of the Chief Inspector, Woolwich, formed a very important part of his duties. Both the Ordnance Board and the Royal Artillery Committee sought his opinion on the questions referred to him, and in less important matters he was frequently directly consulted by the Director of Artillery and Director of Naval Ordnance, who acted on his recommendations without further reference. He was consulted almost exclusively in regard to optical stores. He carried out many of the trials desired by the committees. Climatic trials of ammunition were carried out by the Superintendent of Research, but the Chief Inspector, Woolwich, was usually referred to in such matters, as the principal depository of information as to the behaviour of all munitions in the hands of the services throughout the world.

The Contracts Departments both of the War Office and the Admiralty frequently consulted the Chief Inspector, Woolwich, as to the placing of contracts and occasionally asked him to inspect and report on the works of proposed new contractors and their capacity for undertaking orders. This was especially the case in regard to optical stores, owing to the Inspector of Range Finders' wide experience of optical manufacturers.

As the authority for disseminating information to the services, the Chief Inspector, Woolwich, was responsible for the preparation of paragraphs for the monthly "List of Changes in War Material," and the more frequently issued, "Departmental Changes," as well as a very large number of official pamphlets.

His main duties in regard to the provision of information arose however, from his position as custodian of all specifications, and sealed drawings and patterns of the stores dealt with by him both for the Army and Navy, and his responsibility for keeping them up to date. Specifications were entirely prepared by him, though manufacturing details were usually obtained from the Ordnance Factories.

Drawings of new stores were as a rule obtained from the Ordnance Factories or manufacturers, but were "sealed" by the Chief Inspector, and subsequent amendments to them were made in his drawing offices. The "negatives" of these drawings required for reproducing copies were also held by him, with the exception of those of certain mountings which were held by the Chief Superintendent of Ordnance Factories, an exception which was the cause of some inconvenience at the outbreak of war. The Chief Inspector of Naval Ordnance had started a drawing office in 1913, with a view to eventually taking over from the Chief Inspector, Woolwich, the drawings of all purely naval stores, and as a commencement the drawings of naval shell were gradually being handed over. Specifications were actually kept by the inspector concerned, but drawings were stored by the Equipment Branch.

The inspection authority had a definite place in contract procedure. The Store Department's contract was forwarded to him, so that he might insert details as to pattern. He returned it with copies of specifications and the Contract Department informed him of the tenders issued. The firms tendering applied to him for specifications and drawings, and contractors obtained from him these and other information to guide manufacture. This procedure was cumbersome; but it ensured a clear understanding between all concerned, while failure to observe it led to confusion and eventual delay.

The most important administrative duties of the Chief Inspector, Woolwich, concerned the actual testing and acceptance of new supplies and the inspection of stores in the hands of the services. Individual inspectors were guided by specifications and drawings and sometimes by a sealed pattern. Stores were to differ in no material point from the specification or drawing.[1] The wording of this instruction thus enabled the inspector to use his knowledge, judgment and experience in determining what constituted a material departure. He was merely called upon to certify that the article was "fit for His Majesty's Service." In theory, the decision as to what constituted "material" rested with the Chief Inspector, but in actual practice inspectors had a large measure of discretion. It is on a nice appreciation of where responsibility should be taken that harmonious and efficient working of inspection depends, to avoid on the one hand unnecessary interference with supply, and on the other hand the acceptance of *matériel* that would prove unsatisfactory on service. The Chief Inspector referred cases upon which he felt unable to decide to the Director of Artillery (or Director of Naval Ordnance in the case of naval stores). Naturally in the course of years a large number of precedents had been accumulated which were of much use in determining doubtful points, and in some instances, *e.g.*, the testing of gun steel, definite discretionary limits had been laid down by the Ordnance Board. The actual process of inspection commonly starts with the testing of the material to be used. The process of manufacture is often watched, and then the finished product is examined visually and by measurement or gauging, and finally firing proof is carried out in all cases where the use of

[1] *Regulations for Army Ordnance Services*, Part I., Sec. II.

explosives is involved. One of the most important objects is to secure interchangeability of parts in such stores as guns, carriages, or vehicles so that the replacement of damaged parts can be readily effected.

To prevent unnecessary duplication of staff, much of the Chief Inspector's work in the Midlands and North was carried out by the Naval Inspector of Steel, an interchange of duties to suit geographical distribution having been agreed upon at the time of the transfer[1]. The Inspector of Steel undertook the testing of all metals used by the armament firms for guns, carriages and ammunition and watched the building of guns at Sheffield, Manchester, Newcastle and Glasgow while the Chief Inspector inspected naval guns and shell produced in the neighbourhood of London and carried out firing proof of naval shell and most naval guns.

The actual firing proof of guns, carriages, cordite and cartridge cases was carried out by the Department of the Superintendent of Research, while firing proof of shells and fuses was performed by the Superintendent of Experiments (S. of E.) at Shoeburyness. In each case the responsibility for the nature and the correctness of proof rested with the Chief Inspector. The proof of all small arms ammunition was carried out entirely by the Chief Inspector on his range at Plumstead.

Of the stores inspected by the Chief Inspector by far the greatest portion was sent to Woolwich for examination, delivery being taken by the Deputy Director of Ordnance Stores as the Chief Inspector had no accounting duties. Concurrently with inspection the department carried out packing ready for issue of all small arms ammunition whether made by the trade or the Ordnance Factories, and also the packing and soldering into tin cylinders of fuses, tubes, rockets, lights and articles of a similar description supplied by the trade. It also painted all shell. On completion of inspection and packing stores were handed over to the Deputy Director of Ordnance Stores for storage and issue.

The responsibilities of the department were somewhat restricted in regard to the stores produced by the Ordnance Factories. To obviate the duplication of work by separate Government Departments certain portions of inspection were carried out by the staff of the Chief Superintendent of Ordnance Factories. These included responsibility for material (special exceptions being made of gun steel and finished shell) and the examination of guns and their carriages prior to firing proof. Proof and examination after proof were carried out as for trade productions. The Chief Inspector was dependent on the Chief Superintendent of Ordnance Factories for the erection and repair of buildings, provision of transport, and for the supply of power used in inspection sheds. Inspection gauges were usually both designed and made by the Chief Superintendent to meet the Chief Inspector's demands.

To turn to the inspection of stores in the hands of the services, the somewhat uncertain behaviour of explosives necessitates very

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[1] See above, p. 8.

elaborate regulations for their periodical examination and test. For the drafting of these the Chief Inspector, Woolwich, was responsible, though their actual application (with certain exceptions) lay with Inspecting Ordnance Officers (I.O.O.'s) who were under the Director of Equipment and Ordnance Stores. The results of the inspections and tests carried out by these officers were, however, referred to the Chief Inspector, Woolwich. By recording the results of these local inspections a fund of information was accumulated concerning the behaviour of ammunition under service conditions all over the world, which was of the greatest use in considering questions of design, and points requiring special attention during inspection.

(c) Organisation of the Department of the Chief Inspector, Woolwich, July, 1914.

The details of the organisation of the Chief Inspector's Department in July, 1914, are shown in Appendix I. At this period the staff of the department numbered rather over 1,300 distributed in various grades.[1] It consisted of six divisions concerned with headquarters establishment, guns and carriages, laboratory stores, range finders, chemical questions and equipment. Each division had its own office and office staff and drawing offices. The first three also had various inspection shops in the Arsenal where the practical work of inspection was carried out by a staff of examiners, skilled and unskilled, and labourers, and records were kept by a staff of bookkeepers.

It was a principle of administration that in recruiting the unskilled grades of examiners, preference should be given to men who had served in the Army or Navy, the result being that an appreciable proportion of these grades were Army Reservists who were called up at the commencement of the war. Strong representations were made by the Chief Inspector, on the outbreak of war, as to the great advisability of excepting these men from recall, as their special experience enabled them to be of far greater service to the country in their existing employment, than in the ranks. It was considered, however, to be inexpedient to make an exception in favour of a War Office Department when the rule was being strictly enforced in respect of public and other employers of labour, notably the railway companies, and the request was refused. The consequence was that the staff was seriously depleted, particularly in the Laboratory Stores Division, at a critical stage when the demand for experienced men was hourly increasing, and the department itself had no reserve to fall back upon.

The headquarters establishment was directly controlled by the Chief Inspector. He was personally responsible for the administration and organisation of the whole Department. The conception of his

[1] They were:—One chief inspector, one assistant chief inspector, three inspectors, four assistants to chief inspector, 10 chemists and assistant chemists, one principal foreman writer, five foremen writers, 98 writers, lad writers, book-keepers, lad book-keepers, three chief examiners, 19 foremen and assistant foremen, 641 examiners, 234 other grades and labourers, 300 boys.

position which prevailed at the War Office, and in consequence also in other Departments with which he was brought in contact, is somewhat aptly given in the following words :—

> "It is clear that C.I.W. has always been thought of not as a Department, but as one person who has been allowed, by no means generously, a certain number of assistants, but has been held to be personally responsible in the widest sense for every act and word that is done or said in his name.[1]"

As a result, all communications with outside departments were made by or through, the Chief Inspector, and he was always expected personally to attend all conferences or meetings, where inspection questions were likely to be discussed. He was an *ex-officio* member of the Ordnance and Small Arms Committees.

The Guns and Carriages Division was divided into two sections, both staffed with highly skilled examiners. The one section dealt with all calibres and natures of guns and carried out the actual inspection of guns up to 6-in. in a special shop in the Arsenal, and of guns above 6-in. in a bay of the Royal Gun Factory there. The other or Carriages Section inspected all mountings for field, siege and heavy guns and howitzers, and also the majority of transport vehicles and various miscellaneous stores such as cordage, wire rope, materials in bulk, used by the Ordnance Department, machine tools, leather articles, and the wooden boxes, cases and chests used for the transport and storage of munitions. The section had two shops, one, a large one of some 43,000 square feet area, where field, siege and the smaller fixed mountings could be stripped, examined and measured, and a smaller one for wood work. The larger garrison mountings were examined in the manufacturing shops where they were produced.

The Laboratory Stores Division was the largest division of the department, containing more than half the total establishment. It was sub-divided into five sections[2], each of which had one or more shops in the Arsenal for the practical examination of empty shell and cartridge cases, and filled fuses. Filled shell and cartridges were inspected in the buildings of the Royal Laboratory.

At this period practically all explosive-filled ammunition except time fuses were produced in the Ordnance Factories, and nearly all contract-made ammunition was sent to Woolwich for inspection and proof in order to economise supervisory staff. The system had this drawback, that it necessitated the return to contractors of rejected ammunition for rectification, but at that time trade supplies were always in the hands of experienced manufacturers whose own system of inspection was usually efficient enough to secure compliance with requirements. The difficulty was minimised in the case of stores of which the proof was a more uncertain feature, *e.g.*, time fuses and armour-piercing shell, by bonding the lots at contractors' works until the result of proof was known. Much of the inspection work consisted of gauging the components, which can be quite efficiently performed by unskilled hands.

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[1] HIST. REC./R./900/15. [2] See Appendix I.

The actual details of inspection and proof varied a good deal in the different sections of the Laboratory Stores Division. The Shell Section usually dealt with empty shell of all natures for the land service at Woolwich. The shells were examined, gauged and weighed there. Proof shell were then selected and sent to Shoeburyness to be fired over water for recovery and subsequently returned to Woolwich for 'after proof' examination. After satisfactory inspection and proof, the shells were painted and passed to the store-holder, the Deputy Director of Ordnance Stores. The section had two large inspection shops totalling some 48,000 square feet in addition to a shell-dipping shop for painting medium shell, of some 10,000 square feet.

The Fuse Section also dealt with various other small filled stores such as tubes, primers, detonators, etc. Percussion fuses were practically all made in the Ordnance Factories, whose gauging of the component parts during manufacture was relied on. Time fuses were largely produced by armament firms, but very little inspection was carried out during manufacture, the usual practice being to have a few men at the works to see that the drawing and directions for manufacture were generally complied with. Reliance for satisfactory output was placed on external gauging after delivery, and above all on satisfactory proof results. It is well to draw attention to this as there was in pre-war days no attempt at the meticulous gauging of all component parts which became necessary during the war, when contracts were placed, as had never been done before, for empty fuses and even component parts. The section had eight inspection shops in various parts of the Arsenal, totalling some 30,000 square feet, as well as a proof yard.

The Cartridge Section inspected all B.L. and Q.F., cartridges, filled and empty, though the Ordnance Factories were responsible for the quality of textiles used. The filling of B.L. cartridges was supervised by examiners, the weight of charge being checked and dimensions gauged. The shops allocated to this section for empty cartridge case inspection (filled cartridges were dealt with in Ordnance Factory shops) were three in number occupying some 10,000 square feet in all.

The Cordite and Inspecting Ordnance Officers Section of the Laboratory Stores Division had two sub-divisions with very different duties, the one dealing with the inspection of all cordite gunpowder and guncotton supplied for both Navy and Army, and the other with all reports of periodical inspections and tests carried out by Inspecting Ordnance Officers. The latter also acted as Inspecting Ordnance Officers for the ammunition in the hands of the Deputy Director of Ordnance Stores.

The Small Arms Ammunition Section of the Laboratory Stores Division undertook the whole of the inspection and proof of small arms ammunition both from the trade and from Ordnance Factories. It had for the purpose, a group of shops about 38,000 square ft. in area, and a rifle range on Plumstead Marshes. It also re-examined stores returned from the services or Ordnance Depots. The inspection of ·303 ball cartridge consisted of visually examining, gauging and weighing each

round. For this purpose the shops were fitted with gauging and weighing machines, which were automatic in action and required only unskilled attention. A certain amount of gauging was done by hand, but it was an easy, rapid and machine-like nature of work and could be quite efficiently done by boys, of whom a large number were employed. The average rate of output was 1⅛ million rounds of ball cartridge per week in addition to the accessories, but the machines themselves were capable of turning out approximately 8 million rounds per week.

The Range Finders Division inspected a large variety of instruments and had certain functions peculiar to itself which pertained more to design and manufacture than inspection. The Ordnance Factories had no establishment for dealing with the design or manufacture of optical stores, and in this country there were no trade firms who made a practice of designing instruments for military purposes. Consequently, this division was habitually called upon either to design an instrument for a certain purpose or to elaborate a rough design submitted to the Royal Artillery Committee. It had three shops aggregating some 4,000 square ft., where, in addition to routine inspection work, a certain amount of manufacture and repair work was carried out, such as the curving of position and range finders (a very special nature of work needing highly-skilled operatives), the manufacture of trial samples, the fitting of new lenses and bubbles, and the overhaul and adjustment of binoculars and telescopes. An important duty of the Inspector of Range Finders was to give expert advice in regard to the testing, care and maintenance of coast defence position and range finding installations.

The Chemical Division was the remains of the establishment of the War Department Chemist, which had been transferred to the Chief Inspector, Woolwich, in 1909. Although poorly staffed and inadequately housed and equipped, it performed a very large amount of most essential work, covering a very wide range. In addition to the analysis of all materials (where such was demanded) used in the stores inspected by the Chief Inspector, several other departments, notably the Deputy Director of Ordnance Stores, the Chief Inspector of Equipment Supplies, and the Ordnance Factories, supplied samples for analysis covering an enormous range of materials, such as chemicals, fabrics, paints, varnishes, fuels, lutings, metals and alloys, oils, fats, waxes, soaps, candles, waterproof goods, explosives of all natures, and the ingredients used in their manufacture. The Research Department, with its larger staff and laboratories was the main authority referred to on chemical questions, but in many instances the Chemical Division was called upon to investigate important matters, sometimes in collaboration with the Research Department or Chemical Laboratories of Waltham Abbey or the Royal Laboratory.

Although the Equipment Branch had no actual inspection of stores to execute, it performed duties of an important and varied nature. Many of these were common services for other divisions. The remainder were mainly for the benefit of other departments, or the services at large, and may be broadly described as the collection and circulation of information concerning the stores dealt with by the Chief Inspector, Woolwich.

CHAPTER III.

FIRST EFFECTS OF THE WAR UPON INSPECTION, AUGUST, 1914—MARCH, 1916.[1]

I. Pre-war Estimate of Expansion Requirements.

The outbreak of the war found the Inspection Department very ill-equipped to face the great expansion that was so soon to be forced upon it. Not that provision for such an emergency had escaped attention but the War Office conception of the probable demands on inspection was, as the event proved, singularly inadequate, both as regards their extent and duration. The possible building requirements had been considered at the end of the previous year, and had been limited to a very restricted addition to office space, and certain extensions on a small scale to the existing inspection shops in the Arsenal. In other respects, no great development in the supply of gun equipment was anticipated, but the separation of the Guns and Carriages Division into two distinct divisions, as they had been not long before, was agreed to. Extra gun ammunition it was thought could be provided for by a slight increase in the staff of officers. The possible effect on the supply of small arms ammunition was carefully considered, because the re-arming of the forces with a new pattern small bore rifle was imminent and steps were being taken to equip the shops with special machines for dealing with the new type of ammunition. Arrangements were made to convert these to the ·303 inch pattern in case the emergency should arise before the re-armament was effected. One point was obvious, namely that a largely increased supply of drawings would be at once needed, and arrangements were made for enlisting trade help in their reproduction.

The officer staff of the department consisted of but twenty all told, and that an immediate addition to their number would be necessary was quite clear. To meet this necessity certain officers were earmarked for transfer, some of whom were serving officers and some of whom were on the Reserve List. The actual number was only four, but it must be remembered that officers without previous technical experience were not considered of much value, and the number of these was very small, while the needs of the government manufacturing departments had also to be considered.

II. Expansion of the Home Organisation prior to June, 1915.

(a) Action at the Outbreak of War.

On the declaration of war the approved extensions were at once put in hand, the additional buildings were started, the earmarked officers joined, the small arms ammunition machines contract was changed,

[1] Hist. Rec./H./900/19.

and a definite contract made for the trade supply of copies of drawings at a fixed price. Naturally the existing contracts for warlike stores were all hastened and large additional ones were placed for guns and small arms ammunition and vehicles. The early orders for ammunition were all placed with experienced firms who were accustomed to supplying such articles, but there were other stores, chiefly amongst those handled by the Carriages Section, such as transport wagons, water carts, wheels and stretchers, large supplies of which were at once required and for which recourse had to be made to contractors who were new to government work. Fortunately, for transport wagons a most satisfactory source of supply was found in the various railway companies, which offered to supply some 6,000 G.S. wagons, a number afterwards largely increased. As these companies possessed highly efficient inspection staffs of their own and were under government control, it was agreed that they should be treated as government factories and given responsibility for the material and workmanship of their wagons. Thus the duties of the Inspection Department were reduced to a general supervision to ensure that interchangeability of parts was maintained—a very welcome relief.

The Small Arms Ammunition Section of the Laboratory Stores Division was the earliest to need large extension, as in August, 1914, instructions had been received to prepare for an output of 21 million rounds per week, 8 millions per week then being the utmost capacity of the inspection shops. A large shop was borrowed from the Deputy Director of Ordnance Stores and fitted up with machines as soon as they could be obtained, the small arms range was extended and approval obtained for the erection of a new shop in the Arsenal. An additional building was also obtained for repacking and labelling the small arms ammunition received from America.

Expansion in the Range Finders Division to meet the growth of supplies presented the usual problem of trouble in obtaining skilled workers at the wage that could be offered, but this had been fairly successfully surmounted. Otherwise the chief difficulty experienced was in connection with accommodation. The main workshop, which had been in occupation for several years, had to be given up to the Ordnance Factories, and various small buildings temporarily occupied whilst new premises were being erected. A number of new buildings were being erected on the Marshes near the mekometer house, the view from which was gradually being obstructed in all directions, so that it became necessary to search for another position from which range finders could be tested. A suitable place was found on Shooters Hill, and the whole division was subsequently moved to new buildings erected there for it. The chief abnormal development, beyond the common increase of supplies, was the employment of the division in the purchase of trade supplies of binoculars and later in the examination of the large numbers of telescopes and binoculars that were commandeered under Order in Council.[1] Much designing work had to be undertaken in connection with range finders, sighting telescopes

[1] See Vol. XI, Part III, p. 40.

and other optical stores for anti-aircraft purposes. Later in the year large orders were placed in America for binoculars, for the inspection of which an officer was specially selected and sent to New York. The quality of the output, however, proved very unsatisfactory, the glass used was poor and the workmanship indifferent. Owing to the very pressing needs at the front, a quantity had to be accepted though not up to standard, but it was found necessary to overhaul and rectify these after receipt in this country.

A very severe blow that fell on the department at the commencement of the emergency was the recall to the colours of all Army Reservists and Territorials. As has been pointed out before, it was the pre-war practice to fill all vacancies in the subordinate staff as far as possible with ex-soldiers or sailors, and many of these had not yet completed their army obligations. Fortunately, the withdrawal of these men practically only affected the unskilled classes, but the effect was felt very deeply in the Laboratory Stores Division where the majority of the examiners were unskilled, and where, moreover, the higher grades (overlookers, assistant foremen, &c.), were selected from the best of the third and fourth class examiners. It was not so much that these higher grade subordinates were themselves recalled (most of them had completed their Reserve terms), but that they were inadequate in number for the extended demands, and the field from which addition to their ranks could be made, was so much reduced. Moreover, there was no reserve of experienced (in contradistinction to skilled) men which could be drawn upon to fill the gaps, the nature of work being such that no counterpart existed in civil life. An attempt was made to get assistance from the ranks of viewers employed by the armament firms, but these latter strenuously resisted, and not without reason, the idea of parting with their experienced men. At a slightly later stage an experiment was tried, which met with a considerable measure of success. This was the training of men of qualified mechanic class to fill the positions of overlookers and foremen. From their greater intelligence and mechanical experience it was thought that they would quickly be qualified for positions of responsibility in supervising and checking the work of unskilled men, an expectation that was found to be justified in practice.

(*b*) MODIFICATIONS IN THE STANDARDS OF INSPECTION.

One of the first questions to be considered at the outbreak of war was the extent to which the standard of inspection could be relaxed in order to accelerate output of the large quantities of war material then being ordered. The subject was raised in August, 1914, by the Director of Artillery, who approved of the suggestion made by the Chief Inspector, Woolwich, that the extent of relaxation should be left to his (C.I.W.'s) discretion, with the provision that output was to be accelerated as much as possible, without vitally affecting efficiency. In consequence of this the Chief Inspector issued an instruction to heads of divisions on 23 August, 1914, directing them to take a wide discretion in dealing with their stores, both in relaxing the full routine

of inspection and in accepting stores not fully complying with specification. No definite limits as to how far they might go were laid down, these being left to their individual discretion, subject to the following guiding principles:—(1) nothing was to be done which might vitally affect efficiency; (2) output was to be accelerated as much as possible; (3) all important departures from the ordinary practice were to be referred to the Chief Inspector if practicable before being put into operation; (4) changes affecting arrangements with other departments were to be referred as usual through the Chief Inspector.

Inspectors were to keep notes of the action they found it advisable to take, and acquaint the Chief Inspector verbally from time to time as to what they had done. By this means the Chief Inspector, while delegating very full responsibility to heads of divisions, was enabled to keep in touch with what they were doing, and co-ordinate the actions of the different divisions. One step which afforded much relief to proof work was to increase the size of "lots" of shells, fuses, cordite, etc., and the number of T. & P. fuses fired in proof of each lot was also materially reduced. It was also arranged that ammunition accepted without complete inspection should be stamped with a distinguishing mark, so that if any serious defect were discovered in use, the withdrawal of the batch would be simplified.

(c) FORMATION AND WORK OF NEW DIVISIONS, 1914-15.

As the first need in the emergency was for increased supplies of ammunition, the pressure first became severe in the Laboratory Stores Division, and as a relief to the inspector in charge, one of the sections (Cordite and Inspecting Ordnance Officers), was removed and established, on 10 August, 1914, as a separate division under the senior officer, who became responsible direct to the Chief Inspector. This new division rapidly increased in importance as to it was entrusted the inspection of high explosives, large supplies of which soon became urgently wanted. Prior to the war, there had been practically no high explosive inspection work for the department, the small quantity used, chiefly lyddite, having been provided by the Chief Superintendent of Ordnance Factories, who was responsible for its quality. Trade filling factories were, however, soon established at Faversham and Newcastle, to be followed later by many others, and trade supplies of high explosives were of course required for these, the inspection of which had to be undertaken by the Chief Inspector, Woolwich. High explosives were, however, only subject to chemical analysis. Propellants, on the other hand underwent three separate tests, visual examination, chemical analysis, and proof in the gun, the last two tests being undertaken at Woolwich.

In the Guns and Carriages Division the first few months caused less pressure than elsewhere, what there was falling chiefly on the Carriages Section, and though it had always been the intention to form the division into two, this was not immediately carried into effect, principally because at the moment no officer with previous experience was

available to take charge of the second division. However, early in September, an officer was found, "Carriages" was separated from "Guns," established as a separate division, and put in his charge.

As the early orders for large additional numbers of gun equipments began to materialise very heavy work was thrown on both the Guns and Carriages Divisions, but more particularly the latter owing to the great number of components in a gun carriage, and the amount of sub-contracting commonly employed. It became necessary to organise branches of the Carriages Division in different parts of the country, and by November, 1914, centres had been established at Glasgow, Newcastle, Sheffield, Coventry and Barrow, from which assistant inspectors visited the works in the neighbourhood, at most of which examiners in varying numbers were located. Much difficulty was experienced in obtaining sufficient trained mechanics to satisfy the needs of these two divisions (which as pointed out before employed few of the unskilled class), owing to the larger earnings that could be secured in production work. But indeed this difficulty applied to all classes of labour, owing to the fundamental necessity for employing inspection labour on time work and not on piece work. The almost universal trade practice was to employ piecework, which enabled higher wages to be earned, and the increase of examiners' wages by working overtime was not an attractive substitute. This difficulty was always felt by the Inspection Department throughout the war, and was intensified by the systems of payment by result which were largely employed at a later stage. The work of the Carriages Division grew so much that a deputy inspector was appointed at Sheffield in February, 1915, to control the provincial work in the Midlands, and later in that year additional branches were established at Derby, Leeds, Darlington, Manchester, Gloucester and Birmingham.

The supervision of gun building continued to be carried out in the main by the Inspector of Steel but steps were gradually being taken to relieve him of this work, and examiners were being distributed to Manchester, Sheffield, Coventry and Newcastle. With the advent of proof of guns at contractors' ranges, a serious problem was presented by the necessity for carrying out before and after proof examination at the manufacturers' works. Such operations as taking measurements and impressions of the bore were readily managed, as instruments could usually be borrowed from the firms, and if not were fairly easy to obtain. But it was a very different matter to deal with parts where gauges were needed, such as the breech opening and breech mechanisms. To ensure thorough interchangeability of parts it is necessary to have very accurately made gauges, most of which are very complicated and troublesome to manufacture. Even in peace-time it was not an easy matter to obtain satisfactory gauges, and some even of the armament firms were not consistently capable of producing really accurate ones. With the falling off in workmanship that was so general, it became almost impossible to get such high class work satisfactorily carried out, and various expedients had to be resorted to in order to secure as large a measure of interchangeability as was possible. With the smaller and well established types like the 18-pdr.

and 4·5-in. howitzer, less trouble was experienced, because the makers had pre-war experience of manufacture and possessed their own models and gauges ; but when new patterns were brought in like the 9·2-in. 8-in. and 6-in. howitzers, the guns and mechanisms were finished long before it was possible to get the necessary gauges. Delivery to service of course could not be postponed to wait for these, so the best that could be done was to deal with each maker separately, select the most accurately made gun and mechanism and use it as a model for the rest. This expedient secured interchangeability between each maker's own guns and mechanisms so long as the model could be retained, which sometimes was not for very long when the shortage of guns was acute. It was, however, ineffective as between the output of different makers, but though this no doubt at times caused inconvenience, it was not very serious, as it was generally possible on service to fit guns with mechanisms of the same make.

The position in regard to steel inspection was somewhat differently treated, relief being gained by assistance from the Board of Trade. The production of shell steel had of course increased enormously, and in the usual area of production *i.e.*, the Midlands and North of England, had been most efficiently dealt with by the Naval Inspector of Steel ; but it was soon found necessary to utilise the steel works in South Wales where the Inspector of Steel had no staff. In the acute difficulty of obtaining experienced inspectors this presented a serious problem, which was overcome by the Board of Trade coming to the rescue, and undertaking the inspection of the whole of the steel supply in South Wales. In order to avoid the delay in getting the results of analysis which would have been incurred had the samples been sent to Sheffield or Woolwich (the only two available government laboratories and both much overworked) the services of a firm of analysts at Cardiff were utilised and proved highly satisfactory. Later it was found possible to appoint an assistant inspector to deal with two of the steel companies which were inconveniently situated for the attendance of Board of Trade surveyors. Much assistance was also obtained from the Board of Trade in other parts of the country, where the help of their surveyors was freely given to meet emergencies in the testing of materials, and indeed a few of these gentlemen were temporarily placed entirely at the disposal of the Inspection Department and attached to one or other of its divisions for local work in the provinces.

(*d*) PROOF AT CONTRACTORS' RANGES.

The position of the Royal Arsenal as the important centre of production (Chief Superintendent of Ordnance Factories) of storage and issue (Deputy Director of Ordnance Stores) and of inspection (Chief Inspector, Woolwich) was bound to lead to congestion of its buildings, and communications, an eventuality which of course had been foreseen and means for the relief of which had been considered from the first. As a step in this direction it was decided to prove, as far as practicable, all contract-made guns on contractors' own ranges, instead of at

Woolwich. At that time the firms possessing proof ranges were the Coventry Ordnance Works, at Coventry, Messrs. Vickers at Eskmeals and Messrs. Armstrongs at Ridsdale (near Newcastle) and at Silloth on Solway Firth, but a practical difficulty presented itself in obtaining officers with a knowledge of ballistics to carry out the proof, as the Superintendent of Research was unable to spare any from his staff. An expedient was found by determining on certain fixed charges, which were calculated and made up by the Superintendent of Research from specially selected lots of cordite of proved regularity, and issued to the ranges for use. By this means it was practicable for any artillery officer to carry out the proof of a gun or carriage by carefully following the instructions formulated. The expedient, though not so satisfactory as proof under the supervision of a specially trained officer, proved good enough for practical purposes, though naturally a very close watch had to be kept on the detailed reports which were sent to headquarters at Woolwich. By the adoption of this system some 90 per cent. of the Coventry Ordnance Works and Elswick guns were proved at Coventry and Ridsdale respectively and of Messrs. Vickers' guns made at Sheffield, those fitted with carriages at Barrow were proved at Eskmeals. As a relief to rail transit in the Arsenal it was arranged that Messrs. Vickers' guns from Erith should be sent to the Proof Butts by road. One of the minor difficulties that arose in connection with this matter was the provision of enough crusher gauges and coppers to enable pressures to be taken. A new gauge never gives reliable readings, requiring to be "salted" by being subjected to heavy firing pressures, before being actually relied on for recording purposes, a process that in pre-war days usually took about three months. The supply of such "salted" gauges was not equal to the demand and it became necessary to limit the number of proof rounds at which pressures were recorded. The provision of even untrained officers was a matter of great difficulty, but carriage manufacture was spreading largely and assistant inspectors had been placed at Coventry and Barrow, who were called upon for this duty, being relieved from some of their other duties by civilian assistant inspectors attached for the purpose, while at Newcastle the duty was performed by the laboratory stores assistant inspector. The first Vickers' 12-in. howitzer was proved at Barrow in January, 1915, and the corresponding Elswick howitzer at Silloth about the same time.

(*e*) Congestion in the Royal Arsenal, 1914.

The congestion in the Royal Arsenal continued to increase from the causes already mentioned, added to by the large amount of factory extensions in progress which brought large quantities of building materials, machinery, etc., into the Arsenal. Early in November, 1914, a conference was held between the heads of the Royal Arsenal, namely, the Chief Superintendent of Ordnance Factories, the Deputy Director of Ordnance Stores, the Naval Ordnance Officer and the Chief Inspector, Woolwich (who it may be mentioned were independent authorities owning no common head) to consider what measures could be taken

for relief. The conference was able to suggest some small ameliorations, but the general conclusion arrived at was that little real relief could be effected until inspection and ordnance depots and, above all, filling stations could be provided elsewhere than at Woolwich. Filling of shell had been started at Faversham, and of shell and complete rounds of 18-pdr. at Newcastle, but the proportion of the total supplies so dealt with was small, and the Royal Laboratory still remained the main source of supply of filled ammunition. Whilst this was the case there was little object in inspection of the empty components being effected at the place of manufacture, as they had to come to Woolwich for filling, added to which there was the acute difficulty of finding gauges and trained staff for a large distribution through the provinces. Some relief was, however, effected by dealing with empty ammunition boxes outside the Arsenal, for which purpose a large depot was formed at Tilbury, whence the inspected boxes were brought by barge to the Arsenal and were thus ready to go direct to where they were to be packed, without first going to a shop to be inspected.

(*f*) DIFFICULTIES IN INCREASING STAFF, EARLY 1915.

At the beginning of the year 1915 the staff had not grown equally with the demands upon it, while the orders in prospect had assumed such large proportions that it was clear that very considerable additions to both the staff and accommodation would be needed in the near future. Unfortunately the organization did not include a branch to which administrative questions could be relegated, these together with all executive responsibility being centred in the Chief Inspector; consequently, administrative questions were occupying more and more of the latter's attention, while at the same time technical questions were largely on the increase. The supply of trained and experienced officers was entirely exhausted, and the only other source from which suitable additions could be made were in the ranks of trained civilian engineers. These however, were at the time not easy to obtain (the limitation of salary was a decided obstacle) and moreover required a certain amount of training to fit them for their special duties, which again was difficult to arrange for as the existing staff was more than fully occupied and the available office accommodation was strained to its utmost capacity. The Ordnance College, which might have afforded facilities in this direction had been closed down on the outbreak of war, so that the department had to depend on its own exertions. The need being imperative some solution had to be found, so a small training establishment was formed in the Laboratory Stores Division, and the instruction of such new candidates as could be obtained was taken in hand. The great demand for increased office accommodation could only very partially be met, and to make the most use of what was available, a night shift was instituted for the clerical establishment. At this period (early 1915) War Office approval had to be obtained for all increases of staff, and though as a rule applications for additions met with sympathetic consideration, full reasons had to be adduced in each case, and a certain delay and cramping of effort resulted; thus,

on 31 January, 1915, though a total additional number of 43 officers had been asked for, only 35 had been actually obtained. Some months later the Chief Inspector was given a freer hand to engage what assistance he needed, and thus was enabled to recruit new civilian assistant inspectors to the extent of his capacity for training and accommodating them. A very strict supervision was also kept by the War Office on unusual expenditure in other directions, and the incurrence of financial obligations was not permitted without reference. As an example may be mentioned an application by cable from America, in March, 1915, for leave to hire or purchase a Ford car for the use of the officer in charge of the Pittsburg district, who had a large number of firms to visit daily at considerable distances apart. The Chief Inspector acceded to the request at once by cable, but on reporting the matter to the War Office was instructed to refer such matters in future to them.

(*g*) Increase in Technical Questions.

As the outcome of war conditions, a great variety of technical questions were arising on which the opinions or action of the Chief Inspector were required, amongst which may be mentioned the drafting of new regulations for transport by rail of explosives and filled ammunition, including the small quantities urgently required for proof. The peace regulations were impossibly restrictive and had to be drastically remodelled in consultation with the Railway Executive Committee and the Home Office. The inspection staff was also occupied in making trials and reports on certain novel stores.[1]

The care and preservation of ammunition in the hands of the Field Army at home, in coast defence and anti-aircraft positions, also had to be carefully watched, in view of the inexperience of many of the troops and the unusual conditions of exposure to climatic influences. Special Inspecting Ordnance Officers were also appointed, acting directly under the Chief Inspector's instructions, who toured the country and visited all units in turn. As a result of their reports many instructions had to be issued to provide against abnormal exposure or the misplaced zeal of the troops. As an instance of the latter may be mentioned the case of a Territorial Artillery Brigade who misinterpreted a very simple instruction as to the use of a preservative against damp, and filled the interior of all their T and P fuses with luting, rendering the whole equipment useless.

(*h*) Further Expansions, January-June, 1915.

In March, 1915, contracts were arranged involving a weekly production in England alone of 49 million rounds Mk. VII. ·303 inch cartridges, and the great inconvenience of handling such a vast quantity in the Arsenal in addition to American supplies, and the consequent interference with the already congested traffic there, caused pressure

[1] See below, p. 45.

to be put on the department to inspect at makers' works. When it had been demonstrated that acceptance by supervision of the manufacturers' own inspection would not be satisfactory, it was suggested that an inspection and packing establishment should be attached to each of the big factories and inspection decentralised in this way. This proposal involved great difficulties in the control of these various establishments and in the handling of proof. The points which crop up in the proof of small arms ammunition are frequently abstruse and require an intimate knowledge of ballistics, and there was an absolute dearth of skilled officers to deal with such matters at several centres. Investigation proved that large savings could be effected and rail transit reduced, by carefully laying out the position of the new shops required with regard to each other and to the receipt and issue of stores so as to reduce handling to a minimum. It was therefore decided to deal with all small arms ammunition made in the Arsenal and East London in the shop in the Arsenal, and all the small arms ammunition from the Midlands and North London in some central position, not too far from the Arsenal and the range, so that adequate control could be maintained and proof dealt with, but at the same time more or less on the direct route from the Midlands to the shipping port for France. Such a locality was found at Park Royal, and approval was given for the building at that place of inspection shops and storage sheds. It was at this time, May, 1915, that the establishment of the Small Arms Ammunition Section as a division was determined on and effected. The buildings at Park Royal were designed to be suitable for handling 28 million rounds per week of English ammunition, 18 million rounds per week of American ammunition, and the equivalent quantities of accessories and boxes. The establishment also comprised receipt and issue stores, offices, police buildings, repair shops, boiler house, hospital and canteen, with direct railway access through the goods yard of the Great Western Railway.

These buildings were erected by the Building Works Department of the Royal Arsenal at a very rapid rate, the first sod being turned on 15th May, while inspection actually commenced on 2nd September. This was the first large building extension of the Chief Inspector's department outside the Royal Arsenal and proved very satisfactory in every way. It is interesting also as having provided the first large employment of women on inspection work. At the end of November, 1915, information was received that the supply of English ammunition would increase to 90 million rounds per week, and further extensions were arranged. By the addition of further machines the capacity of the Arsenal shops was increased to 25 million rounds per week, and arrangements made to extend the Park Royal buildings, the original designs of which had been so drawn as to admit of almost indefinite expansion, to a capacity of 66 million per week.

During the year 1915 an increasing amount of work fell on the Guns Division through the introduction of trench mortars, an entirely new type of weapon of which many patterns were tried, the experiments with which had to be carefully followed. But it was not until the following year that these were produced in any great

numbers, and on the whole the pressure on the Guns Division, though great enough, was less overwhelming than in the Laboratory Stores Division. It was on this account that, as a relief to the Inspector of Laboratory Stores, the special section which had been formed to deal with bombs, grenades, &c., was detached in November, 1915, and put under the Inspector of Guns. The work of this section at the time, though important, was hardly sufficient to warrant its establishment as a separate division, and the stores with which it dealt were of a distinct type which rendered separation from the Laboratory Stores Division easy to accomplish. Moreover, trench mortars and the ammunition for them were developing simultaneously on lines quite apart from gun ammunition, and there was a distinct advantage in having both dealt with by the same inspector.

Pressure in the Laboratory Stores Division had been heavy and continuous, not only on account of the increasing quantity of ammunition to be inspected, but also because of the introduction of numerous new types of which no previous experience existed and for which new systems of inspection had, in many cases, to be evolved. Specifications were in such cases hard to prepare, and needed constant alterations as the idiosyncrasies of the article became known in handling supplies. Also, cases of failure of ammunition were reported from the front which necessitated long and exhaustive investigations, with all of which the division was closely associated even if not primarily concerned.

The great development of trench warfare stores, naval mines, and aerial bombs, which had little in common with gun ammunition, rendered it desirable to establish a separate section to deal with them. This was formed in the spring and was known as the Grenades Section. A separate section was also formed at Newcastle to deal with ammunition filled by the Elswick Ordnance Company, and the filling of shell had to be supervised at Faversham.

It was also found necessary to form separate though smaller sections to deal with the selection and preparation of test pieces, with the design and provision of gauges and with the provision and issue of samples for the use of contractors.

The need for new buildings in the Arsenal to meet the increasing quantities of ammunition and a rapidly growing staff threw a great deal of administrative work on the head of the division, in addition to his technical work, and in order to relieve him to some extent the Small Arms Ammunition Section, which was assuming large proportions, was taken from his control in May, 1915, and established as a separate division under an inspector.

The Chemical Division experienced a good deal of difficulty in coping with the enormous increase of analyses of all kinds, which was appreciably affected by the greatly extended use of high explosives, on account of the limited laboratory accommodation and the lack of attraction that the low salary that could be offered presented to qualified chemists. No spare ground existed round the laboratory on which building could be extended, but it was found possible to place an additional storey over part of it and some 60 per cent. of extra bench

accommodation was obtained. With much trouble some additional chemists were secured, who were later added to when authority was given to slightly increase the commencing salary, so that by the end of 1915 the staff had more than doubled. As the accommodation had not increased equally with the staff it was found necessary to work a night shift. These increases, together with some relief obtained by employing certain outside agencies for analyses, were sufficient to meet the situation, for the time.

III. Arrangements for Overseas Inspection, 1914-15.

(a) Institution of Inspection Arrangements in the United States of America.

Very early attention was paid to the American continent as a possible source of supply, and a week after war was declared an order for 20 million rounds of ·303-in. ball cartridge was given to the Canadian Government, and a similar one (afterwards largely extended) placed with the Remington Arms Union Metallic Company, of Bridgeport, Connecticut. It was at first arranged that inspection on both these contracts should be carried out by Major Ogilvie, who had been lent to the Canadian Government by the War Office a year previously for inspection purposes, and was attached to the staff of the Chief Inspector of Arms and Ammunition. The Chief Inspector of Arms and Ammunition, however, very soon pointed out that the great distance between Quebec and Bridgeport made it impossible for one individual to supervise both contracts. Accordingly, it was arranged that Major Ogilvie should deal with the Canadian ammunition, and that an officer with a small staff should be sent from home to deal with the Bridgeport supplies. Fortunately, it was found possible to secure a small number of weighing and gauging machines for their use, as some were in course of supply for Canada, and the Canadian Government agreed to hand these over. Very shortly afterwards orders were also placed in America for various shells of the smaller calibres from 18-pdr. to 4·7-in., and an officer with a staff of examiners with gauges had also to be detailed to supervise these. The two parties sailed for America in the middle of September, 1914.

Other orders soon followed and created further demands for personnel for the United States, which proved a severe tax on the small supply of experienced officers and men available at Woolwich, and the small addition that had been made to the former in August was soon exhausted. In view of the necessity for keeping an experienced staff in England, where not only was the main source of supply, but where expert knowledge was required to deal with changes of design and the introduction of numerous new forms of ammunition, it was decided that it was impossible to send to America complete staffs of officers and men who would be capable of full inspection of the supplies. To rely entirely on locally engaged labour for final inspection was highly inexpedient on account of the doubtful feeling towards the Allies on the part of a large proportion of the working classes in

America, and the consequent fear of sabotage. A middle course was therefore adopted of sending out small but experienced nucleus staffs who could engage a certain proportion of reliable local assistance, generally supervise the output and fully inspect a percentage, in order to check the manufacturers' own inspection, on the thoroughness of which great stress was laid; final examination and acceptance for the service were to be carried out in England after receipt. Providing these staffs with gauges was a difficult problem, as not only did they require ordinary inspection gauges but also sets of check gauges to test those provided in America.

In the winter of 1914, the contracts placed in America began to assume large proportions, an order for 1,000,000 complete rounds of 18-pdr. shrapnel being placed with the Bethlehem Steel Company, and large quantities of propellants being ordered from the Dupont de Nemours and Hercules Powder Companies. It became evident that the few officers already sent out would be quite unable to deal with what was in prospect, and it was decided to send out a more senior officer (with the title of Deputy Chief Inspector) and a larger staff. As the main contract above mentioned was for complete rounds, including cartridge case, primer, propellants, shell, and fuses, it was necessary to arrange for a proof range suitable for testing fuses and shell, as well as facilities for testing cartridge cases, primers, and propellants, the latter being nitro-cellulose instead of cordite. The Bethlehem Steel Company had, close to Bethlehem, a proving ground for guns on the lines of the proof butts in England, and this company discovered a place on the coast near Cape May where a fair range for shell and fuse proof could be obtained. Steps had to be taken to provide the necessary guns for proof purposes, viz., 18-pdr., 4·7-in. and 60-pdr., which were with some difficulty obtained from Canada. Lt.-Col. Phipps, the officer selected for this charge, sailed from England with a small staff at the end of December, 1915.

(*b*) Inspection in Canada, 1914-15.

Orders for munitions in Canada commenced, as has been already mentioned, with an order for ·303 small arms ammunition, but this was soon followed by others for gun ammunition, chiefly 18-pdr. shrapnel shell, cartridge cases, primers, and fuses, and later again for shell forgings and shell from 4·5-in. upwards. These orders were placed through the Canadian Shell Committee, which was formed soon after the outbreak of war by the Canadian Minister of Defence. As there was an established Government Inspection Department in the Dominion under the Chief Inspector of Arms and Ammunition, it was decided that it was unnecessary to send a staff from England, and that inspection should be entrusted to the Chief Inspector of Arms and Ammunition as representing the Chief Inspector, Woolwich. With the Chief Inspector of Arms and Ammunition was the British Officer already mentioned, Major Ogilvie, who had had considerable experience in the Woolwich Inspection Department, and to him was assigned the responsibility for dealing with the British orders. For the most part

he employed Canadian inspectors, but these were reinforced by a few officers and examiners sent from England, chiefly to be employed in connection with the inspection and proof of fuses. Reference was constantly made to the Chief Inspector, Woolwich, on all technical questions. It was not long before friction arose between the Shell Committee and the inspection authorities, partly in connection with primers and partly on account of alleged overstrictness in inspection generally, but more particularly in regard to steel for shell. The Shell Committee had adopted the system of ordering the different components of primers from different firms, and sending these to one or two firms who were only employed on assembling the parts together. Components were examined by a firm of inspecting engineers acting for the Shell Committee, while the finished primers were subject to inspection by the Inspection Department. Such an arrangement is always liable to lead to trouble, and it did not fail to do so in this case; the assembling firms had great trouble in making successful use of the components supplied to them, and were much disappointed when the best results they could obtain often failed to satisfy inspection. At Major Ogilvie's request a senior officer, Lieut.-General Pease, an officer who had had a large experience of inspection, sailed for Canada in May, 1915, and after investigating local conditions and the situation generally, was able to adjust matters so that for a time smooth working was ensured. In November, 1915, upon the establishment of the Imperial Munitions Board, directly responsible to the Ministry, Major Ogilvie, with the staff working under him, was transferred to the Board, being promoted to Lt.-Colonel and appointed Chief Inspector. Inspection was thus placed under the Imperial Munitions Board, but with the proviso that full control in all technical matters rested with the Ministry of Munitions. Although, perhaps, not an ideal arrangement, it worked well, largely owing to the personality and experience of the Chief Inspector, and remained in force until some little time after the reorganisation of the home Inspection Department in March, 1916.[1]

(c) DEVELOPMENTS IN AMERICAN INSPECTION, 1915.

To turn to the American side, an enormous amount of administrative work had to be undertaken by a very attenuated staff. It was necessary to organise a department on the lines of that at Woolwich, but with this difference, that in the main the inspection carried out was not to be final so far as issue to the service was concerned. The stores dispatched from America were to be subject to final examination and proof (to a varying degree according to the article) on arrival in this country. Arrangements had been made by the Bethlehem Steel Company to provide Colonel Phipps with an office, and he was supplied with copies of all the proof, inspection, delivery and other kinds of forms used in this country. He had, however, to arrange for the amendment of these to suit American methods and for the printing of a supply. The suitability

[1] See below, p. 80.

of the ranges, also provided by the Bethlehem Steel Company, had to be established. One at Cape May was used for the proof of shell and T. & P. fuses, and one at Reddington, near Bethlehem, for the proof of guns, propellants, cartridge cases and primers. The provision of inspection gauges was placed on manufacturers by a clause inserted in all contracts, but the gauges had to be tested, and only a small supply of check gauges existed for the purpose. An office staff had to be organised, a chemical laboratory established, and a considerable amount of local assistance engaged, besides a host of minor matters calling for rapid arrangement. To effect all this, the only staff that could be spared were seven officers, some fifty examiners, a chemist and two writers, but they were all selected as being experienced in their special branches, and for the orders then in prospect formed a strong nucleus for local expansion. The great drawback was that for supervising gun and propellant proof no trained officer could be found at home other than Colonel Phipps (it was not till much later that the Superintendent of Research was able to extend the numbers of his staff), so this duty devolved on him personally, seriously occupying his time and interfering with his other duties. Later in the year, a novel expedient for proving shell was adopted at Reddington by firing them into sand butts, which proved of great advantage when the range at Cape May was found to be unsatisfactory for shell recovery proof, owing to a large proportion of the fired shell being lost. This was effected by specially adapting certain proof guns, by reducing the chamber capacity and length so that the requisite proof pressures could be obtained with a muzzle velocity sufficiently low to avoid damage to the shell on striking the sand.

Little more than two months was available for this preparatory organisation before the great extension of American orders commenced. From March, 1915, onwards very large orders for complete rounds of 18-pdr. ammunition, shell of various calibres up to 12-in., shell steel billets, fuses, nitro-cellulose, cordite, etc., followed one another in rapid sequence, and in spite of this it was impossible to meet the need for additional experienced officers, though with great difficulty some half-dozen were secured and sent out. In the light of after events, it would have been wiser to have sent out a number of civilian engineers to undertake the duties requiring less military experience, such as steel and shell inspection, but Colonel Phipps was strongly of opinion that inexperienced inspectors sent from home were of no use to him, and that he could do better in this direction by engaging local engineers. This latter expedient did not, however, prove entirely satisfactory, partly through difficulty in obtaining Treasury sanction for the salaries required, which seemed very large in comparison with the analogous ones in England, and the staff in the United States remained for some months much too attenuated for the work that had to be performed. In spite of this, inspection on the lines determined on previously kept pace with production, and supplies were not delayed. As a rule these supplies were quite satisfactory, but in a few cases the percentage examination, which was all that could be applied, failed to secure satisfactory results. The important exceptions related to empty graze fuses, of which a large number had to be

rectified after inspection in this country, and to 6-in. base adapter shell, of which one maker's deliveries were found to be very badly fitted. To these might be added certain complete rounds of 18-pdr. H.E. shell, which were suspected as the cause of prematures, but a very careful and prolonged examination failed to reveal any defect likely to be the cause of such failures. All fuses were fully examined on arrival in England (except filled T. and P. fuses), and a great proportion of the shell, whilst all the propellants were visually examined and re-proved for determination of charge.

IV. Effects of the Formation of the Ministry of Munitions, June–December, 1915.

(a) PARTIAL TRANSFER OF THE RESPONSIBILITY FOR INSPECTION, JUNE-JULY, 1915.

The formation of the Ministry of Munitions on June 5, 1915, had a very important effect upon the work of the Inspection Department. It was then laid down that the staff to be transferred to the new Department should include the Chief Inspector at Woolwich, the Chief Inspector of Small Arms and their staff, so far only as they were engaged upon the actual work of inspection.[1] At this date the War Office reserved to itself the responsibility for the kind and quality of the munitions supplied to the forces.[2] Accordingly, when arrangements were made for the actual transfer of inspection duties to the Ministry on July 5, it was agreed that the fixing of designs and specifications, as well as the research and experimental work of the inspection authority should remain with the War Office, that no relaxation of specification or tests (including proof) should take place without the concurrence of the War Office, and that the approval of the War Office should be obtained before new inspectors were appointed.[3] While the administrative work of inspection was thus transferred to the Ministry, the technical duties of the inspection authority, and particularly the responsibility for standards, were still the responsibility of the War Office.

In determining on the method of placing the new orders on behalf of the Ministry, one of the first essentials was to make adequate provision for inspection, and the Chief Inspector, being personally charged with responsibility for all arrangements, was constantly in consultation with the Director-General of Munitions Supply and the heads of the various branches into which the new Ministry was divided. This demanded his constant presence in London, with a consequent interference with his very heavy duties at Woolwich. At the end of June he submitted proposals to the Director of Artillery for the delegation of a large measure of responsibility to the officers in charge of divisions and a corresponding raising of their status. At this time the transfer of inspection to the new Ministry was being considered, and a few days later (5 July, 1915) became an accomplished fact. These

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[1] M.W. 1374. [2] See below, p. 48. [3] M.W. 1374/5.

proposals were forwarded by the War Office to the Ministry and strongly supported by the Master-General of the Ordnance, but at the time no action was taken upon them.

(b) Decentralised Inspection in the Munitions Areas, June, 1915.

The first action of the Ministry of Munitions was to exploit all possible sources of ammunition supply. The country was divided into areas, and local Boards of Management and Munitions Committees appointed in all the main manufacturing districts. This made it essential that the system of local inspection (with which some progress had been made) should be very largely extended. The Laboratory Stores Division was already very heavily burdened and it was inexpedient, even if not impossible, to expand it to the extent that would be required to cope with the new situation. It was therefore decided to constitute a new division, with its headquarters located at some convenient centre in the provinces, to deal with unfilled ammunition components, shells, cartridge cases, &c. The possibility of starting separate divisions in each area was considered, but discarded on account of the impossibility of obtaining sufficient administrative staff to supervise at several different centres. Not only did this latter consideration apply to the individual to be put in charge, but also to the higher grade subordinate staff, such as head writers and chief examiners. No skilled military officers were available for this new division, as the insistent demands of the American organisation had absorbed the few that had become available. It was therefore decided that only one division should be formed, and that it should be officered entirely by civilian engineers who could be rapidly trained to carry out the inspection of empty ammunition components on the approved lines without being concerned in questions of efficiency of designs. Sheffield was fixed upon as the locality for the headquarters, being in a good central position, and also convenient from the fact that the headquarters of the Inspector of Steel were there as well; branches were to be established at all the main centres of production. The new division was formally constituted on 29 June, 1915, under an Inspector of Munitions Areas, and its organisation was very rapidly carried out. Offices were secured at Sheffield, the headquarters installed there on 12 July, and branches were quickly opened throughout the provinces, numbering some twenty in all and ranging from Aberdeen to Bedford, and Dublin to Ipswich. At first it was intended that the new division should deal only with the stores produced by the local committees, but its sphere of operations was soon extended to include the productions of the armament firms whose supplies were still coming in large quantities to Woolwich. A much needed relief was thus given to the congested state of the Royal Arsenal. One of the largest Munitions Committees was that of London, and owing to its distance from Sheffield, and proximity to Woolwich, it was decided not to place this under the control of the Inspector of

Munitions Areas, but to deal with it by a special section appointed for the purpose and attached to the Laboratory Stores Division. The demand for drawings by the Munitions Committees was very great indeed and it was arranged that these should be issued by the Inspector of Munitions Areas, a large stock being provided for him by the Equipment Branch. However, it was soon found possible to reduce the number issued by devising a form of paper "negative," which the committees could easily reproduce for themselves, and thus multiply drawings for their own purposes. The main lines of the organisation for inspection thus arranged by the end of July, 1915, appear in Appendix II. The expansion that was effected in the Chief Inspector's department during the first twelve months of the war may be more readily grasped by comparing the distribution set out in Appendices I and II, which show in skeleton form the arrangement of the department at two different stages—in July, 1914, and in July, 1915. The total strength of the department at these two periods was respectively, in approximate figures, 1,300 and 9,000.

(c) THE SUPPLY OF DRAWINGS AND GAUGES FOR AMMUNITION, JULY, 1915.

At this time (July, 1915) the supply of drawings and an adequate number of inspection gauges were two questions that had assumed proportions of great magnitude. The first was with difficulty met by a further recourse to trade reproduction (assisted by the system of paper negatives above mentioned), and some slight increase of reproducing plant at Woolwich; lack of space, however, at the time prevented an adequate development of the latter. The gauge question was much more serious, and the want of a national gauge factory, capable of expansion, was very acutely felt. The Ordnance Factories, the original sole source of supply, had certainly increased their output, but only to the extent of some 300 per cent., and the Chief Inspector had been driven to searching the country for gauge makers, and placing contracts wherever he could get work undertaken. The requirements for the output of the new Munitions Committees were so great, that it was recognized that they were beyond the powers of the Inspection Department to deal with; moreover, the contract and supply work involved was not a proper inspection function, and therefore the supply of gauges was undertaken by the Ministry. A full description of the result is given elsewhere,[1] and need not be repeated here, except to remark on the enormous assistance that was given by the National Physical Laboratory.

Inspection of the large supplies of gauges that were foreshadowed was quite beyond the facilities existing at Woolwich, but the Director of the National Physical Laboratory, who took a keen personal interest in the matter, undertook to carry out examination of both inspection and check gauges at Bushey Park, and an establishment was set up at that place which proved of inestimable benefit.

[1] Vol. VIII, Part III, Chap. I.

(*d*) Further Decentralisation.

One of the early actions of the Ministry was to develop the filling of ammunition at various places in the provinces, which entailed the provision of a large number of sections located at the factories to inspect the output. As this was not work that could be undertaken by the Inspector of Munitions Areas (the personnel of that division having no experience of explosive work), the duty of finding these devolved on the Laboratory Stores Division.

The work of grenade inspection was also growing very rapidly, both in the establishments for inspecting empty bombs and grenades all over the country and at Woolwich, and also in the various grenade filling factories which were springing up around London and near Birmingham. These additions to the Laboratory Stores Division rendered it desirable to relieve it where possible, and as mentioned previously, the Grenades Section was in November, 1915, transferred to the Guns Division.

The development of all these new filling factories necessitated the despatch to them of large quantities of high explosives and propellants. The system of sending samples of the former to Woolwich entailed a waste of time which caused congestion at the makers' works, the latter being mostly ill-provided with storage accommodation. A suggestion that use might be made of the provincial Universities, was investigated with most successful results, and after a conference in London between the representatives of the Universities and the Chief Inspector a definite arrangement was made that the Universities should take over the local inspection of all high explosive supplies in their neighbourhood. The chemists of the Universities attended at Woolwich for a short course of instruction in the special processes necessary, and the new system was put into operation in August, 1915. It was arranged that the Universities should only give acceptance sentences on material that fully complied with the specification, supplies outside the specified limits and any doubtful points being referred to Woolwich; periodical samples were also sent to the Inspection Department Chemist to enable the latter to take check analyses and thus preserve an even standard throughout. The Universities, whose assistance was thus secured, were those of Liverpool, Leeds, Manchester, and Birmingham. For propellants all proof had to be carried out at Woolwich, so there was no advantage in local analysis, but the despatch of bulk supplies to Woolwich was avoided by selecting samples for firing proof and analysis at the makers' works, sending these only to Woolwich and carrying out visual examination locally. By this means it was possible to send supplies either direct to filling factories, or to certain large stores which had been provided at various places by the Explosives Supply Department. Supplies of propellants from America were handled in the same way, going direct to the explosives stores and being visually examined there.

(*e*) Arrangements for Inspecting Swiss Fuses.

A further extension abroad was effected in August, 1915, by the placing of contracts for empty fuses in France and Switzerland,

the latter of which assumed considerable proportions. Inspectors had to be found to supervise the manufacture, but it was decided to be impracticable to carry out full inspection at the place of production. The contracts were therefore so drawn as to provide for payment only after satisfactory examination of deliveries in England. The assistant inspectors sent out (three in number) were limited to testing the material employed, and exercising a general supervision over manufacture so as to establish a *prima-facie* justification for the despatch of supplies. There was also considerable development at home in the inspection of empty fuses outside Woolwich, chiefly at Luton and in London; one of the largest establishments was at Perivale, where the supplies of American and Swiss fuses were examined after delivery in this country.

V. Difficulties and Delays.

During the whole of this period (June to December, 1915) the work of the Inspection Department was beset by new, and to some extent unexpected, difficulties.

(*a*) Effects of the Introduction of new Gun Designs.

The technical work of the inspection authority in regard to the design of guns and carriages was particularly laborious. The output increased rapidly during the whole of 1915, as manufacturing facilities developed, and at a greater rate as the year progressed. In actual numbers the majority of the equipments delivered were of the lighter and well-established designs, namely 18-pdr. guns and 4·5-in. howitzers. Apart from the ever-present trouble of securing sufficient skilled mechanics to swell the number of examiners, no serious problems were presented by the 18-pdr. gun; but the new designs of heavy howitzers which were got out during the year, entailed a great deal of technical work. The demand for weapons of this type was so great that the designs were somewhat hastily adopted, in fact the urgency existing was so great that it was not possible to carry out sufficiently protracted trials to establish their suitability in all respects for the conditions of active service. The consequence was that constant amendments were necessary, and it became extremely difficult to control the issue of drawings to contractors and the alterations of contracts. This trouble was augmented by the large number of individual drawings required for a complete equipment (amounting to several hundreds) and the prevalence of sub-contracting with carriage manufacturers. It was quite common for the prime contractor's orders for material or for certain parts to be sub-let several times over, which made it extremely hard for the inspector to trace the hands through which the work was passing and to keep track of all that had to be attended to. Careful instructions were always issued for the contractors to supply full particulars of all sub-orders placed, but frequently these were neglected or misapprehended, a prolific source of complaints of delay. Another fruitful source of complaint was the

trouble of getting working drawings of all the parts of new equipments and subsequent amendments from the designer. Approvals were commonly given on the trial of a sample, with an insufficiently dimensioned sketch design, and it often took weeks and sometimes months to get a properly dimensioned working drawing capable of being reproduced and issued to govern contracts. It constantly happened, therefore, that long intervals supervened between the granting of an approval and the issue of drawings in accordance with it. The last mentioned being the duty of the Inspection Department, the latter usually got the blame, although the real cause was entirely outside its control.[1] To show the growth of the work done the following figures of equipments which passed inspection may be given :—

Nature.	1914.	1915.
12-in. howitzer	—	22
9·2-in. howitzer	—	32
8-in. howitzer	—	32
6-in. (26 cwt.) howitzer	—	4
60-pdr. gun	—	120
4·5-in. howitzer	40	553
18-pdr. gun	43	2200

(*b*) Difficulties in regard to Gun Ammunition.

With the advent of large numbers of new and inexperienced manufacturers, all animated with a keen desire to meet the crying need for large supplies of ammunition, and extremely anxious to get tangible results in the shortest possible time, it is not surprising that complaints soon began to be made of delays and over-strictness on the part of the Inspection Department, which rapidly increased in number and acerbity. As to over-strictness it was perhaps natural that commercial firms who were accustomed to the wide limits and greater laxity permissible in most trade work, should find it hard to realise the necessity for the great exactitude demanded in gun ammunition components, or for the absolute soundness of the whole material used. The pre-war standard both of quality and workmanship was undoubtedly very high, and exacted by strict inspection ; and though in many respects relaxation was at once possible, there was a natural reluctance on the part of those responsible for quality to proceed to extremes without practical experience of the effect on safety and efficiency. The necessity for enormously increased production could, however, only be met by some lowering of the pre-war standard, and gradually relaxations, both of quality of material and standard of workmanship, were introduced, and were increased from time to time as experience seemed to justify. On the other hand, in some respects the pre-war standard of inspection, when components had been made in well-equipped factories by highly skilled workmen, were found to be undesirably lax, notably in the case of fuses, in connection with which it was ultimately found necessary to impose a very strict gauging of small parts, and extremely rigid and complete inspection of detonators throughout the whole process of manufacture.

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[1] See below, p. 98.

With the urgent and insistent demand for rapid supplies of all war-like stores, it was inevitable that the process of inspection should be found an irksome and irritating hindrance. Its necessity was, of course, generally (though not invariably) admitted, but for a long time there was a common failure to realise that it is one of the essential stages of production for which time must be allowed just as much as for the processes of actual manufacture. In pre-war days this was fully recognised, and legislated for, a permissible period for inspection of 61 days being the general rule. Such a large limit during the exigencies of war was, of course, inadmissible, but it was claimed by the Inspection Department that a space of a fortnight was a very moderate allowance for the performance of inspection, including proof, a claim that undoubtedly was not unreasonable. That the department was, on the whole, able to keep within this is shown by a memorandum of 3 February, 1916, in which it was stated as follows :— "Looking at the figures of the weekly returns, the average floating stock of the department is about two weeks' supply, in some cases it is much less, in others it is more; in the main it is keeping pace and has kept pace with deliveries." There is no doubt that there were occasions when issues were delayed unduly through waiting for inspection to be concluded, sometimes for want of personnel, but more often through lack of essential gauges, the shortage of which was extreme but was not the responsibility of the department. Experience has shown that contractors are as a rule very optimistic as to their capacity for output, and on failing to realise their estimates, it is not surprising that to a very obvious though unavoidable obstruction like inspection was attributed responsibility for the failure. This was much intensified when the system of sub-contracting was, as it was in many instances, largely extended. It must be recognised, however, that contractors in most cases genuinely felt that they had a grievance, and not entirely without reason, for with only previous commercial experience to go upon it is hardly to be expected that they would realise beforehand the interference that would be entailed by the strict examination at all stages that service stores required. Inexperience in the recognised methods of procedure led to omissions and mistakes which it took time to rectify; contractors failed to notify inspectors, often were ignorant whom to notify, and so on. Such complaints not infrequently met with a ready acceptance by the local Ministry officials charged with hastening production, which encouraged their force and frequency, and it became a common practice to attribute to inspection delays quite a large proportion of failures to realise estimates. Nor were there wanting unscrupulous people who were not averse from seizing upon a convenient excuse which lay ready to their hand to cover their own shortcomings. Numberless cases of complaint were investigated, and in the great majority of instances were found to be either unjustified or relating to matters outside the control of the department. A significant commentary on the crop of complaints against the Inspection Department that arose after the formation of the Ministry of Munitions is afforded by the fact that in practically all cases they originated with new and

inexperienced contractors, and that practically none were received from the older established firms on government work.

(c) Congestion at the Royal Arsenal, June-December, 1915.

In spite of the large diversion of stores from the Royal Arsenal effected by the arrangements which have been mentioned above, the quantities being received still continued to be greater than the facilities for coping with them. Great congestion in all departments resulted, which engaged the anxious attention of the Ministry. Visits of investigation to the Arsenal were made by Mr. W. T. Layton in August, and later in the beginning of October by the same gentleman, accompanied by Messrs. Judd and Lewis. Their enquiries chiefly concerned the methods of handling, transporting, storing and despatching the enormous quantities of material constantly being received, and also included the serious discrepancies between the quantities reported as delivered by contractors and the amount of inspected material leaving Woolwich. The issue was to some extent confused by the "paper work" of the Inspection Department, *i.e.*, completion of inspection notes, being seriously behind the completion of inspection, but also by the amount of transiting within the Arsenal itself between "filled" and "empty" storehouses, the inspection sheds, and the filling departments; added to which consignments were often weeks on the railways before they entered the Arsenal. It must be remembered that there was only one railway entrance, and the various buildings, having grown up in the course of years, were very ill arranged to secure the minimum of movement and handling. There was evidence of want of co-ordination between the four independent authorities in the Arsenal, but the investigating committee were unable to ascertain the exact causes of congestion, nor did they think it could be arrived at and remedied until a new system of store-keeping and stocktaking was introduced. The reports by Mr. Layton were afterwards considerably elaborated so far as the Inspection Department was concerned by Mr. (later Sir John) Mann, Financial Adviser to the Ministry.

In view of the expected enormous increase in inspection arising from increased production, the Director-General of Munitions Supply decided that expansion and revision of inspection and its organisation must be taken in hand at once. A conference was held on 16 October, 1915, between the Director-General of Munitions Supply, the Chief Inspector, Mr. Mann, and the heads of other departments concerned. The general principles then arrived at were the centralisation of inspection administration at headquarters, as the natural consequence of the centralised control over filling and component production; the systematic decentralisation of inspection, either at contractors' works or at other local centres so that Woolwich should become only one of many local centres, although the Arsenal was to remain the centre of inspection of various special stores for which it was properly equipped, and a reorganisation of the Chief Inspector's Office at Woolwich.[1] A few

[1] C.R. 4452.

days later the Chief Inspector submitted a long report to the Director General of Munitions Supply fully describing the situation and its most pressing needs, with proposals as to how they could best be met. The most insistent demands were:—

(1). Increased office accommodation, and additional officers and clerical staff.

(2). Full delegation of responsibility to officers in charge of divisions with a rise in status.

(3). Appointment of an administrative officer in the Laboratory Stores Division.

(4). Large additions to the staff of the Inspector of Munitions Areas and the Deputy Chief Inspector in America.

(5). Removal of headquarters to London.

It was pointed out that the officers of the Inspection Department who were competent to deal with the technical questions remained practically as they were at the commencement of the war, and the overwork to which they had been subjected for more than a year was reaching the limit of human endurance. The Chief Inspector himself seldom worked less than fifteen hours a day, heads of divisions were mostly similarly overstressed and some relief of administrative functions was essential. The second proposal required submission to the Treasury, and whilst it was being further considered action was immediately taken in some other respects. A large addition to the office accommodation (practically doubling the existing space) was obtained in the Arsenal. This was secured by obtaining on loan from the Deputy Director of Ordnance Stores a floor in his largest warehouse. An increase of wages was approved for the clerical staff, which enabled more writers to be obtained. A branch of the Ministry was charged with obtaining 100 more engineers, and the keeping of cost accounts was suspended. The removal of headquarters to London was not carried out, because the Ministry itself was rapidly increasing and room could not be found, while the increase of space at Woolwich above mentioned eased the situation there.

VI. Reorganisation, December, 1915—March, 1916

(*a*) Transfer of Responsibility for Standards to the Ministry, December, 1915.

The proposals for a general raising in status of the whole Inspection Department, more in conformity with its increased responsibilities, was still under consideration when, early in December, 1915, the control of design and the standards of inspection was transferred from the War Office to the Ministry of Munitions, and Major-General (later Sir John) Du Cane was appointed Director-General of Munitions Design.[1] The two Inspection Departments, those of the Chief Inspector,

[1] See below, p. 54.

Woolwich, and the Chief Inspector of Small Arms, were placed under one head, Brigadier General F. F. Minchin, as Deputy Director-General of Inspection. This officer was directly responsible to the Director-General of Munitions Supply in regard to all administrative matters and to the Director-General of Munitions Design for the questions formerly reserved to the War Office, *i.e.*, standards of quality, the qualification of inspectors and the confirmation of appointments.[1]

Action on the Chief Inspector's proposals of the previous month for the raising of the status of the department generally was postponed and the Deputy Director-General of Inspection requested Messrs. Phipps and Carr of the Education Department to report on the organisation of the Chief Inspector's Department with the object of discovering how best further to carry out the separation of administrative from technical functions, and of making any further suggestion for accelerating the actual progress of inspection and passing of stores. Messrs. Phipps and Carr made a careful investigation and on 18 January, 1916, submitted a very elaborate report in which they reviewed the situation as it stood, and made certain minor suggestions for the improvement of the organisation in general. The main recommendations, however, affected chiefly one division and the central office and were :—

(1). A rearrangement of the duties in the overtaxed Laboratory Stores Division, with a view to relieving the stress on the heads of the division and sections.

(2). A decentralisation of the registry and clerical work of the office with a view to expediting the handling of correspondence.

The two great difficulties in immediately coping with the main recommendations were pointed out in a memorandum from the Chief Inspector which dealt with the whole subject matter of the report. These two difficulties were increase of personnel and space to accommodate it. However, very shortly afterwards, the recently acquired office space had been converted and fitted up, which enabled the clerical organisation to be extended and remodelled.

The large increase in the area of buildings occupied by the Department of the Chief Inspector at Woolwich is yet another measure of the expansion which took place between July, 1914 and March, 1916. The inspection shops and offices occupied when the war broke out covered some 230,500 square yards ; by March, 1916, this area had been almost quadrupled, and had reached 859,500 square yards. This figure excludes the large new inspection bonds distributed all over the country, and makes no allowance for the additional space taken up in the filling factories, where inspection proceeded in the

[1] Mr. Collinson's Papers, No. 7. (These unregistered papers are now filed in the Archives Registry.)

factory itself. A large proportion of the increase was due to the extensions for inspecting small arms ammunition.[1]

(b) SEPARATION OF LABORATORY STORES DIVISION INTO "TECHNICAL" AND "SUPERVISORY," FEBRUARY, 1916.

The requisite increase of personnel could only be slowly achieved, but by some alteration in the senior staff an additional head was found for the over large Laboratory Stores Division, and the latter divided into two parts, Technical and Supervisory. This arrangement, imperatively dictated by the force of circumstances, is not an ideal one, and there is much to be said for the other possible alternative suggested in the report, of dividing the organisation into two parts each of which should exercise both technical and supervisory functions with regard to a moiety of the stores.

The objection to the latter alternative is that the close relation between all the different components that go to make up a complete round of ammunition renders it inadvisable to separate the responsibility for their inspection under two independent authorities. As to the former alternative, which was the one adopted, the objection is that technical knowledge is largely obtained by the actual handling of stores in practical inspection, and a total loss of this experience by the Technical Branch would in course of time tend to attenuate its own capacity and transfer it to the Supervisory Branch. To guard against this it was arranged, when making the separation, that all proof both of empty components and filled ammunition should remain in the hands of the Technical Branch, and that it should also issue all inspection directions. A close co-operation between the two branches was essential for the efficient working of the new system, and a constant interchange of experience and ideas between not only the heads of the two divisions, but also the heads of the corresponding sections, was arranged for. The actual separation into two Divisions of "Technical" Laboratory Stores and "Supervisory" Laboratory Stores was effected by a Departmental Instruction on 2 February, 1916.

(c) NEW RANGES FOR SHELL PROOF, FEBRUARY, 1916.

Among the steps taken towards decentralisation was the establishment of new proof ranges. The increase in production of shells during

[1] The details of the expansion are as follows :—

Division.	Area occupied in square yards. July, 1914.	March, 1916.
Shells	48,000	123,000
Empty Cartridges	10,000	52,000
Filled Shell and Cartridges	2,000	4,000
Fuses	26,000	71,000
Grenades	2,000	9,500
Miscellaneous Stores	8,000	8,000
Small Arms Ammunition	38,500	414,000
Guns	33,000	56,000
Carriages	52,000	52,000
Range Finders	5,000	28,000
Offices	6,000	42,000

the latter part of 1915 caused the facilities for recovery proof at Shoeburyness to be severely overtaxed, even though the proportion of proof rounds fired had been largely reduced by increasing the size of "lots." Also, when the final inspection of shells was completed in the provinces the transit of proof rounds to Shoeburyness caused a certain amount of delay in obtaining results. Means for remedying these troubles were considered, and it was found feasible to establish recovery proof ranges for 18-pdr. and 4·5-in. shells at Boston, in Lincolnshire, and at Silloth, on Solway Firth. These ranges were established in February, 1916, under officers supplied by the Superintendent of Experiments, and not only greatly relieved the congestion at Shoeburyness, but also expedited the release of shell bonded at the various depôts in the Midlands and North of England.

(*d*) Reorganisation in March, 1916.

Although the recommendations for the delegation of responsibility and raising of the status of the Inspection Department had not been carried into effect, it was, on the whole, in February, 1916, in a better and stronger position than it had been. However, while able to cope with the supplies coming forward, the higher staff was still overworked and had not been sufficiently strengthened on the administrative side. The amount of supervisory work was increasing steadily with the decentralisation of inspection. A more drastic and far-reaching form of re-organisation was felt to be necessary and was considered beyond the scope of the powers of the department to carry out for itself.[1] This consisted in its recognition by the Ministry of Munitions as, in itself, a department not merely in name, but in fact, organised in all its branches under competent and responsible heads. The opportunity for the further devolution of responsibility and the raising of the department as a whole (on the lines previously recommended but to a more extended degree) was afforded by its inclusion in a new civilian department equal in standing to the other main branches of the Ministry. This re-organisation was carried into effect near the end of March, 1916, when the administration of inspection was placed by the Minister of Munitions in the charge of Sir Sothern Holland, whose staff was organised as the Inspection Department of the Ministry of Munitions as follows :—

Director-General of Munitions Inspection, Sir R. Sothern Holland.
D.D.G.W. Administration, Mr. H. Ross Skinner.
D.D.G.X. Technical, Colonel J. R. Stansfeld.
D.D.G.Y. Organisation, Mr. A. H. Hadley.
D.D.G.Z. Small Arms, Colonel G. H. S. Browne.

The headquarters of the department were established at the offices of the Ministry in Whitehall Place.

The relations between the Inspection Department and the Department of Munitions Design were governed by the same

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[1] Mr. Collinson's Papers, No. 7.

principles as those agreed on between the Ministry of Munitions and the War Office at the time of the first transfer of the inspection staff in July, 1915, that is the Department of Munitions Design retained certain rights as regards approval of designs and specifications, the standard of inspection, and the appointment of inspectors. The total strength of the department at the time was 19,000. Later years saw an even greater expansion in the numbers of the staff, but the principles underlying the re-organisation were maintained throughout the war.[1]

[1] See below, Chapter VI.

CHAPTER IV.

RESEARCH AND DESIGN, 1914–15.

The preceding chapter has related the gradual expansion of the organisation for inspecting munitions and its complete absorption at the close of 1915 into the Ministry of Munitions. In the meantime, the departments concerned with research and design had been passing through similar stages in their development, and it was ultimately the need for a close co-operation between officers concerned with the quality and those responsible for production that led to the transfer to the Ministry in December, 1915, of duties relating both to the standards of inspection and to the development and approval of patterns.[1]

I. First Effects of the War on Design.

But little change in the design of artillery material had apparently been anticipated during a war. It was only in respect to engineering stores that arrangements were made for any increase of design duties within the department of the Master-General of the Ordnance, as a result of changes in pattern during the course of hostilities. It had, on the other hand, been foreseen that the stores provided by the Quarter-master-General would be subject to change while war continued as well as after its cessation. Even so, it was ordered that officers normally engaged upon technical matters, such as the design of motor transport, should be absorbed into the staff concerned with supply upon the outbreak of hostilities.

(*a*) Developments of Pattern, August-December, 1914.

Accordingly, design work during the autumn of 1914 was mainly concentrated upon bringing to completion important patterns already under consideration. Trials of T.N.T. were hastened, and in September, 1914, this explosive was accepted as a substitute for picric acid by both services.[2] An attempt was made to introduce into British manufacture a new small-bore rifle which was already in experimental supply. This was a weapon of low trajectory and extreme accuracy, which had been developed as a result of the experience of the South African war, but had not been introduced into service by reason of the unsatisfactory nature of its ammunition. It did not prove practicable to turn over to the manufacture of the new model; but a modification known as the 1914 pattern, was evolved for American manufacture, the details being adjusted by representatives of the Royal Small Arms Factory and of the Inspection Department. The specification for this pattern was approved on 22 October, 1914, and the design finally accepted in the following March.[3]

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[1] See below, p. 53. [2] Vol. X. Part IV. pp. 4-8.
[3] Hist. Rec./H./170/5; Hist. Rec./R./1420/10.

The very first incidents of the war brought with them an urgent requirement for weapons of a new type. The immediate need for long range weapons for service in the field was met at first by taking 6-in. guns from coast defences and mounting them upon railway carriages, extemporised by the Ordnance Factory.[1] The experimental 9·2-in. howitzer known later as "Mother" was sent to France late in the year and used as a model for further manufacture.[2] Mountings were evolved for guns of heavier nature, which were being adopted for land service.[3] With the increased use of high explosive ammunition new designs of shell and fuses had to be developed for field guns. The fuse difficulty was temporarily overcome by combining time fuse No. 80 with the direct action fuse No. 44, an arrangement devised during the autumn and formally approved in October, 1914.[4] The whole system of detonating H.E. shell was under revision. In December, 1914, patterns were approved for a gaine, not before used in British service, and for a graze fuse (No. 100).[5] The enemy's superiority in regard to machine guns was experienced at once. In October, 1914, the establishment of siege conditions along the whole of the Western front gave rise to the need for entirely novel weapons, trench mortars, grenades and the like. For many of these no patterns existed and designs were worked out hurriedly without any basis on past experience.[6] Many of these new explosive stores, such as trade designs of hand and rifle grenades, signal and other illuminating cartridges, parachute rockets and bombs, were submitted direct to the Inspection Department for trial and report, possibly because the section of the Directorate of Artillery concerned (A.3) was unaccustomed to dealing with the Ordnance Committee, partly also because the Inspection Department was best equipped for carrying out such trials.

(*b*) PRACTICAL DIFFICULTIES IN DEVELOPING DESIGNS DURING HOSTILITIES.

In time of peace, the War Office had relied almost entirely upon the Ordnance Factories and the armament firms for the origination of patterns, which needed the skill of the expert combined with the manufacturer's knowledge of workshop practice. When hostilities began, these same factories were the sole sources of output. The interests of immediate production were paramount and experimental work took a second place.[7] This was particularly the case while the Master-General of the Ordnance and his officers were of the opinion that the war would be over before the lengthy investigations necessary could produce any definite result.[8] Moreover, small

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[1] 121/Stores/215.

[2] 121/Stores/215. HIST.REC./R./1000/118.

[3] *Ordnance Board Minutes, passim.*

[4] *Ordnance Board Minutes* 11629.

[5] Vol. X., Part V., Chap. V.

[6] Vol. XI., Part I., pp. 2–3, 34–36.

[7] Thus, for example, a proposal to develop a pattern of trench mortar on the lines of a German drawing was rejected in August 1914, in view of more immediate demands on the capacity of the Ordnance Factory and armament firms. (Vol. XI., Part I., p. 34).

[8] *Ordnance Board Minutes*, 11989, 12302.

experimental orders must necessarily have been less attractive to armament makers than the contracts which were being placed for manufacture on a large scale. Even the capacity of the Research Department was partly utilised for production. Thus, for example, a semi-industrial plant, which was improvised by the department in December, 1914, provided the Ordnance Factory with a large proportion of pure T.N.T. for exploder bags for nearly a year, being of as great importance in regard to supply as to research.[1]

Very grave difficulties attended any attempt to evolve or modify patterns. It was impracticable to make any alterations which affected ballistics either for the troops on active service or for the new armies, which were in course of training. Hence, for example, it was impossible to simplify the new design of rifle bullet so as to obtain the ideal pattern having two components only, the envelope and the core.[2] When, however, a change became absolutely necessary, great ingenuity was displayed in producing designs which should involve no alteration in ballistics and should comply with other essential conditions. Thus, in May, 1915, the Research Department worked out a new form of cordite to be made from the solvent ether-alcohol instead of acetone but to have the same calorimetric value as well as the same ballistics as the existing service cordite.[3]

As the war went on, the business of the Ordnance Board, and experimental work generally, became greatly congested by reason of the changes in pattern which were needed to facilitate manufacture as well as to meet experience in the field. Not only was the manufacture of samples delayed by the urgent need for bulk production, but the work of the drawing offices attached to the Ordnance Factories and the Inspection Department fell into arrear. The completion of design was greatly hampered by constant amendments. Thus, for instance, the No. 100 fuse, which was urgently needed, had been approved as a service store in December, 1914, but actual manufacture was delayed by numerous modifications in design which were made between January and April, 1915, so that output of the empty fuse did not begin until June, 1915, and issues were not made until the following August.[4] The spreading of contracts to firms other than armament firms and the later development of group manufacture thrust upon the drawing offices at Woolwich a mass of unusual work in regard to the subdivision of drawings. The utilisation of new firms, inexperienced in the fine class of work needed for military standards, added enormously to the work of the design and inspection authorities in regard to pattern, since tolerances, gauges, and the design itself often needed modification to satisfy the conditions obtaining in the shops of the new contractors. The consequent delays in issuing drawings were so great that in May 1915, the Admiralty established its own drawing office at headquarters, which was gradually developed to include the simpler classes of design work, while naval matters which were more complicated or those needing prolonged research were still referred to the Ordnance Board, the Chief

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[1] Vol. X., Part IV., p. 7.
[2] Vol. XI., Part VI., Chap. II.
[3] Vol. X., Part IV., p. 3.
[4] See Appendix V.

Superintendent of Ordnance Factories and the other officers concerned with design at Woolwich.[1]

(c) Action to Supplement the Normal Design Organisation.

The establishment of a designing office at the Admiralty was only one of many efforts made on all sides to speed up the work of design and invention, for which the existing organisation was obviously insufficient. Even the soldier in the field was experimenting on new types of weapon for trench warfare, improvising ingenious weapons, many of which were of a dangerous and inefficient character which would not have justified their provision by the responsible authorities at home.[2] The development of stores to suit the new conditions of warfare seized the imagination of the private individual. The work of designing and producing such stores was allocated late in the year 1914 to a distinct sub-section of the Department of Fortification and Works (F.W.3.A.).[3]

Scientific experts had been called into consultation in November, 1914, when the General War Committee of the Royal Society was appointed to "organise assistance to the Government in conducting or suggesting scientific investigations in relation to the War, the Committee to have power to add to their number and to appoint sub-committees not necessarily restricted to Fellows of the Society." Among the sub-committees appointed was a Chemical Sub-Committee, members of which had investigated the uses of irritant substances and had evolved the British lachrymator, S.K., before the German gas attack in April, 1915.[4] On 28 December, 1914, the Secretary to the Committee on Imperial Defence suggested the formation of a small expert committee to design devices suitable for the new type of warfare,[5] and the need for such a committee of engineering officers and other experts was urged by the First Lord of the Admiralty (Mr. Winston S. Churchill) on 5 January, 1915.[6] A small committee consisting of the Director of Fortifications and Works, the Director of Artillery and the Assistant Director of Transport, was instructed to consider one of the devices then suggested, *viz.*, a machine-gun destroyer or cross-country vehicle; but these investigations were abandoned as a result of certain unsuccessful trials.[7] Mr. Churchill, however, set on foot experiments in regard to several classes of land service stores, such as shields and armoured cars for service with the Royal Naval Air Service, and in February, 1915, established the Admiralty Landships Committee, which in time developed the cross-country vehicle or tank.[8]

The difficulty of sifting out the numerous suggestions of all kinds which poured into the Admiralty and the War Office was enormous. The small fraction which deserved experimental investigation for naval purposes were referred by the Admiralty to H.M.S. Vernon, the National Physical Laboratory and the War Committee of the Royal Society;

1 Hist.Rec./H./1122/97, p. 66.
2 Vol. XI., Part I., p. 3.
3 *Ibid*, p. 7.
4 Hist.Rec./H./1650/8.
5 Vol. XII., Part III., Appendix I.
6 *Ibid*, Appendix II.
7 *Ibid*, pp. 14–17.
8 *Ibid*, p. 8.

but the procedure of the War Department remained practically unaltered and, save for co-operation between the Chemical Sub-Committee of the Royal Society and Section F.W.3.A. of the Directorate of Fortification and Works in regard to chemical warfare, little use was made of the Royal Society's committee for military purposes.[1]

A general realisation of the importance of munition supply grew with the spring campaign of 1915 and led to the formation of the Ministry of Munitions in June, 1915. It brought with it, also, a public demand for the organisation of the country's inventive capacity for the purposes of the war.[2] About this time the Commander-in-Chief set up an Experimental Committee at General Headquarters to deal with inventions and the application of modern science to the needs of war. Public opinion was generally in favour of a similar organisation at home, and leant towards the establishment of an independent department of scientific experts to serve both the Admiralty and the War Office.[3] On 22 June, such a scheme was definitely formulated by Mr. A. J. Balfour, then the First Lord of the Admiralty. He suggested that a Board should be established with the two-fold office of investigating the utility of inventors' proposals and of formulating practical demands for new devices.[4] The formation of the Admiralty Board of Inventions and Research under Lord Fisher was announced by the Press Bureau on 18 July. Shortly afterwards a similar but independent organisation was established under the Ministry of Munitions.

II. The Place of Design in 1915.

It was agreed upon the establishment of the Ministry of Munitions in June, 1915, that the Army Council should remain responsible for the kind and quality of the stores supplied. The fixing of designs and specifications and the tests to be applied, as well as research and experimental work, were still the functions of the War Office.[5] The officers of the Munitions Supply Department of the Ministry, who were responsible for providing guns, ammunition, rifles and small arms, were thus entirely dependent upon the War Office authorities for decision and investigation in respect of the patterns and specifications of these stores.

(*a*) Distinct Treatment of Inventions and Novel Devices.

While it was thus accepted that the Army Council should remain responsible for the kind and the pattern of standard warlike stores, the application of the same principle to inventions and novel devices was found to be impracticable. Where knowledge of the technique as well as of the manufacture of a store was practically nil, production could be only successful when controlled by those who were in close touch with the development of design. Accordingly arrangements were made to place with the new Ministry of supply responsibility for inventions generally and for the design of trench warfare and chemical warfare stores in particular.

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[1] 1/Gen. Nos./1541.
[2] See, for example, *Times*, 12 June, 1915.
[3] 1/Gen. Nos./1541.
[4] *Ibid.*
[5] M.W. 1374.

During the months of June and July, some steps were also taken to strengthen the organisation within the War Office for dealing with inventions. It was, however, recognised that, while the wants of the troops should be formulated by the Army itself, as was already being done by the Experimental Committee at General Headquarters, public opinion would only be satisfied by the establishment of an independent body of civilian scientists to deal with the requests so formulated and with proposals received from inventors at home. After attending an exhibition of certain devices at the Royal Naval Air Service experimental ground at Wormwood Scrubs on 30 June, Mr. Lloyd George agreed that the Ministry should undertake the responsibility for continuing that experimental work on land service stores, which had till then been undertaken by the Admiralty.[1] It had already been proposed that the Ministry should include an Inventions Department for military stores, and on 28 July, Mr. Lloyd George announced that the War Office was handing over the whole question of Army inventions to this branch of the Ministry.[2] He had, indeed, been informed (6 July) that the Secretary of State was prepared to abandon the project for strengthening the small Inventions Branch of the War Office and to appoint instead a *liaison* officer between the Experimental Committee at General Headquarters, the War Office and the Inventions Department of the Ministry, which it was then understood would be under the control of a military officer of rank similar to that of Lord Fisher.[3]

Nevertheless, the means to be employed in correlating the work of the Admiralty Inventions and Research Board, the proposed Inventions Department of the Ministry, the Experimental Committee at General Headquarters and the War Committee of the Royal Society continued under discussion during July and the greater part of August, and in the meantime the organisation of the Inventions Branch at the War Office proceeded. Eventually on 6 August, the Inventions Department of the Ministry was established under a civilian controller (Mr., afterwards Sir Ernest, Moir) advised by a panel of technical experts. The War Office Inventions Branch was not, however, transferred to the Ministry; but general promises were given of assistance from the military authorities, and the responsibility of the Ministry for the land warfare inventions with which the Admiralty had previously dealt was confirmed. The Army Council reserved the responsibility for deciding whether an invention was of practical service under the actual conditions of warfare and for some months the functions of the new Inventions Department of the Ministry were extremely limited.[4]

The principle of distinguishing between research as to novel devices and the modification of standard designs was more definitely maintained in the case of the special appliances for gas and trench warfare. The sub-section F.W.3.A., which was dealing with these, was

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[1] See Vol. XII, Part III, p. 24. This arrangement was formally accepted by the Admiralty on 17 July, and by the War Office on 20 August.
[2] *Parliamentary Debates* (1915), H. of C., LXXIII, 2370.
[3] 1/Gen. Nos./1541.
[4] 1/Gen. Nos./1541; HIST.REC./R./263·8/7; *Ibid.*, 700/27.

transferred to the Ministry *en bloc* in July, 1915, and formed the nucleus of a new department for trench warfare supplies. The design of trench mortars, their ammunition and the service patterns of grenades was reserved by the Director of Artillery.[1] The new department's responsibility for research was based on the admitted impracticability of severing this duty from that of supply in the case of experimental weapons,[2] and it interpreted its functions very widely. Its energies during the summer and autumn were concentrated upon developing and producing as quickly as possible simply made stores, such as the 4-in. Stokes mortar with smoke ammunition, cylinders filled with liquid chlorine and large numbers of emergency grenades.

(*b*) New Problems in the Design of Standard Stores, January-November, 1915.

In the meantime, the research and design authorities under the War Office were investigating a rapidly increasing number of problems which arose out of the military position from day to day.[3] Experiments were carried out as to mountings for the heavy guns and howitzers, which were being introduced into field service, as to the designs for use in repairing ordnance which was injured or worn and as to patterns of weapons recovered from the enemy or lent by the French Government. All classes of design work became much congested. The normal procedure of reference from the Directorate of Artillery to the Ordnance Board, the Chief Superintendent of Ordnance Factories and Chief Inspector, Woolwich, became more and more subject to delays, as the other business of these officials grew. Comparatively little increase was made in the experimental staffs during this period. Thus, for example, considerable difficulty was experienced in obtaining skilled calculators to relieve the two officers of the Proof and Experimental Section of the Research Department, Woolwich. Their work covered practically all investigations concerned with ballistics and increased rapidly during 1915, with the introduction of greater variety in guns and propellants, whilst they also gradually absorbed the work of designing the interiors of new guns. The complexity of such investigations prohibited haste, since the answer to one single question referred to the Experimental Section by the Ordnance Board might involve over 120 calculations.[4] On the other hand new designs, which were hurriedly improvised during this period of stress were necessarily to be regarded as makeshifts only, as was for instance, the case with the 13-pdr. (9-cwt.) guns, which were converted from 18-pdr. Q.-F. guns for anti-aircraft purposes.[5] Again, the rigidity of established design procedure tended to fix as standards for general manufacture the extemporised weapons which were built up from any available stores by the troops in the field or by the Ordnance

[1] Vol. XI. Part I. p. 8.
[2] M.W. 6495.
[3] *Annual Report of the President, Ordnance Board,* 1915, *passim.*
[4] Information received from Research Department, Woolwich.
[5] Vol. X., Part VI., pp. 27, 32.

Factories and thus to perpetuate elements which were undesirable both from the point of view of use and manufacture. Notable cases in point are those of the 3·7-in. and 4-in. trench mortars.[1]

While the normal work of modifying or initiating patterns was thus increased by the exigencies of the military situation, the position in regard to manufacture was giving to the whole question of design an important aspect, which had previously received but little consideration. While entire reliance had been placed upon the Ordnance Factories and British armament firms for manufacturing the stores for which they were specially equipped in regard to *personnel*, machinery and labour, comparatively little attention was given to simplicity of design, beyond that which was demanded by the Chief Superintendent of Ordnance Factories or Chief Inspector, Woolwich. Moreover, it had been the custom of the armament firms to interpret for themselves the drawings issued with their contracts.[2] Numerous changes in pattern were, however, required to enable manufacture to proceed in the United States, to which the War Department early turned for supplies or in the general engineering shops of great Britain, which were gradually converted to munition manufacture from the spring of 1915 onwards. The armament makers themselves also applied for certain alterations to facilitate output on the huge scale required and with the materials available. The newly introduced contractors had not the experience themselves to subdivide sealed drawings or to make the necessary alterations to suit their manufacturing conditions without departing from the military standards, as had been the custom of the armament firms. A very considerable number of changes to facilitate manufacture were considered and approved by the design authorities. Thus, for instance, the temporary omission of base-plates was allowed and parallel-walled 18-pdr. shells were introduced in order to facilitate block-filling.[3] The modification of specifications with a view to extending sources of supply was also a matter for consideration in conjunction with design.

The final decision as to the desirability of modifying designs to meet the needs of production thus rested with artillerists, whose personal knowledge of the use of weapons was necessarily greater than their familiarity with the conditions governing manufacture. It was maintained that it was only by giving greater weight to considerations of safety and efficiency than to those of supply that the confidence of the Army in its weapons could be secured. The experience of the Egyptian campaign of the '80's had shown that military control over design was essential, if military responsibility for the success of the campaign was to be upheld.[4] On the other hand, the immediate provision of stores in far larger quantities than had ever been anticipated gave a new importance to conditions affecting supply. So long as the Master-General of the Ordnance was responsible both for the quantity and the quality of munitions the decision between

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[1] Vol. XI, Part I, pp. 35, 36.
[2] Mr. Collinson's Papers, No. 10.
[3] *Annual Report of the President, Ordnance Board*, 1915, *passim*.
[4] Sir C. Harris, November, 1915 (1/Gen. Nos./1605); see above, p. 7.

these two conflicting elements remained with a single authority. The advantage of unified control was diminished as the duties relating to supply outgrew the normal methods of his directorate, and was entirely lost when responsibility for supply was vested in a distinct civilian Ministry in June, 1915.

It was almost inevitable that an independent supply authority should experience difficulty in impressing the needs of the manufacturing position upon the officers whose first concern was to maintain high standards of quality. This difficulty had already been experienced in regard to high explosives.[1] Under normal conditions, military authorities had had little difficulty in obtaining all the picric acid necessary and investigations in regard to design had been mainly concerned with safety and efficiency. In September, 1914, decision was taken to use T.N.T. instead of picric acid, without any serious investigation as to the practicability of obtaining the new explosive. In October, 1914, the absolute lack of manufacturing capacity for T.N.T., and the vastly increased demand for high explosives led to the establishment of an authority for their supply, which was only nominally dependent upon the Master-General of the Ordnance. The new Committee on High Explosives, thenceforward, devoted a large part of its energies to persuading the design authority to admit the use of the new explosives, which could be readily and cheaply obtained, as alternatives to the service explosives of which the supply would eventually be insufficient. Much concentrated research was given to the problem ; and the solution was not finally reached till 1917. In 1915, opinion differed as to whether the war would last so long as to allow these researches to materialize. Individual applications for changes in the specification for explosives to facilitate production were meantime considered on their own merits, and were occasionally made after very serious delay.

It was the practice to consider on its own merits each manufacturer's application for simplifying design. During the summer of 1915 the general extension of munitions manufacture and the development of public interest in producing warlike material brought into particular notice the questions of standardising design and simplifying patterns. As a result of a Parliamentary question on this subject, the practicability of simplifying stores was referred to the Chief Inspector, Woolwich, in September, 1915. Some proposals were made immediately for modifying the design of rifles, swords and lances with a view to facilitating manufacture,[2] but detailed suggestions for standardising and simplifying munitions in general were not set out by the Chief Inspector, Woolwich, until the following December, when the machinery for design was being reorganised.[3]

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[1] Vol X., Part IV, Chap. I.

[2] 84/Gen. Nos./4492.

[3] D.G.M.D./Gen./22. It was represented in this memorandum (16 December) that shrapnel 18-pdr. and 60-pdr. shell were too difficult to manufacture under war conditions, that driving bands were too complicated, and that certain cartridge cases were unnecessarily complex and could be as efficiently made by simpler methods. It was, however, pointed out that simplification did not necessarily result in immediate improvements in output or decreased cost, since it usually involved exhaustive trials and the making of new tools.

In the meantime, experience in the field was proving the quality of certain munitions, particularly H.E. shell and fuses, to be far from satisfactory, both in regard to efficiency and safety. A series of prematures and blinds which occurred in France, from August, 1915, onwards, threw serious suspicion upon both the No. 100 fuse with gaine and the double fuse (No. 80-44). In October, a shortened form of gaine was authorised, in November the use of a 10-grain detonator below the gaine was sanctioned and shortly afterwards the acceptance of any more long gaines was forbidden.[1]

III. Transfer of Design Functions to the Supply Authority, December, 1915.

While these developments were progressing it was considered by the Minister of Munitions (Mr. Lloyd George) that the output of munitions was being seriously hampered by difficulties which were experienced by his supply officers in getting decisions on urgent questions of design. He contended for the general principle that the relations between the Ministry of Munitions and the Army Council should be those that previously existed between the Master-General of the Ordnance and the General Staff.[2] It was pointed out that experience had shown that the expeditious and efficient supply of munitions required the transfer of the functions of the Ordnance Board and the War Office with respect to design, specification, provision of samples, testing and so forth to the Ministry of Munitions. Serious delays had already occurred in the supply of essential munitions owing to the divorce between design and manufacture.

> "Every day that passes, questions, small or large, arise in connection with the production of munitions which require reference to the Ordnance Board ; in great part they are questions arising out of difficulties of manufacture demanding adjustment or alteration of design . . . such as to type of detonator, modifications of fuse, gun carriage, or so on. Sometimes they are suggestions for improvement which occur in the course of manufacture. The settlement of these things should be under the same authority as that which is responsible for the manufacture and supply of the goods concerned. . . . . The setting out of design, the drawing up or altering of specifications, the provision of patterns and the final testing of the completed article are essentially processes belonging to manufacture and supply. To have the first processes of supply outside the Department responsible for supply is bound to lead, with the best will in the world, to delays and difficulties."[3]

Towards the end of November, 1915, while the Prime Minister (Mr. Asquith) was acting Secretary of State for War, decision was

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[1] See Appendix V.

[2] HIST.REC./R./263.8/3.

[3] Memorandum by Parliamentary Secretary of the Ministry of Munitions (M.W. 1374/12).

accordingly taken to transfer to the Ministry of Munitions responsibility for designs, patterns and specifications, for testing arms and ammunition and for the examination of inventions bearing on such munitions, while the Army Council was to remain responsible for the general nature and amount of the weapons and equipments required. Field trials of new stores were to be arranged between the two Departments and provision was to be made for the representation of the Army Council on advisory committees under the Ministry.[1] On 29 November 1915, the new duties in regard to design were formally undertaken by the Ministry and the control of experimental and research bodies, such as the Research Department, Woolwich, was also transferred from the War Office.[2] The change was not made without protest on the part of the military authorities. The Master-General of the Ordnance pointed out that most of the suggestions as to change of pattern and specification which were referred to the War Office by the Ministry emanated from manufacturers and were almost invariably in the direction of relaxing the terms of the specification and pressing for the acceptance of an admittedly inferior store, accompanied at times by a reduction in the factor of safety. The Assistant Financial Secretary (Sir Charles Harris) maintained that to move the point of contact between the two Departments would not eliminate friction. It was the function of the Master-General of the Ordnance to balance the conflicting requirements of the Army's needs, the development of artillery science and the practical conditions of manufacture in decisions as to design. The Ordnance Board was his organisation for the scientific study of these questions, taking into account the knowledge gained from theoretical study, experiments on specimens and the practical experience of the manufacturer and the user. Manufacturing questions were accordingly a part only, and that not the most important part, of the Board's work. To make the civilian department, which supplied munitions, responsible for design rather than the Army which used them would be to head straight back to the weakest feature of the regime of the civilian Surveyor-General of Ordnance. Though his department was staffed with soldiers to a far greater extent than the Ministry and was part of the War Office, the result of the system as seen in the Egyptian campaigns of the '80's was that the Army lost all confidence in its weapons, and the military authorities not being responsible for the weapons, could not be held responsible for the campaign. He suggested that, if the Ordnance Board were working imperfectly, the remedy lay in strengthening and supporting it, *e.g.*, by direct representatives of the Ministry, rather than in altering its position.[3]

Despite these protests, the necessity for expediting methods of supply in November, 1915 was so overwhelming that the authority of the supply Department over design was definitely established. A Department of Munitions Design was formed within the Ministry of Munitions under the control of General (afterwards Sir John) Du Cane,

[1] Hist.Rec./R./263·8/3; M.W.1374/12. [2] 1/Gen. Nos./1607.
[3] 1/Gen. Nos./1608.

who till then had presided over the Experiments Committee at General Headquarters, France. The Ordnance Board was dissolved on 4 December, 1915,[1] and reconstituted as the Ordnance Committee, an advisory body to the Director-General of Munitions Design on military matters and to the Director of Naval Ordnance on naval questions. Administration of the experimental and research establishments was transferred to the Ministry. It had originally been intended that the remaining duties of the Master-General of the Ordnance should be distributed between the General Staff and the Quartermaster-General. Upon the return of Lord Kitchener from the East, it was, however, decided to retain the Master-General of the Ordnance and his technical staff within the War Office. As a result, the design of munitions and all power connected with such questions rested with a junior officer, whose status as Director-General of Munitions Design was inferior to that of the Master-General of the Ordnance, who, while he was a member of the Army Council, had no real power, and was only a channel of communication between the Army in the Field and the Ministry of Munitions.[2] The main problem which arose from the revised arrangement was that of securing sufficiently close touch between the Ministry and the Army in the Field.[3] The direct result of the re-organisation was to expedite the important decisions which were essential to the successful equipment of the forces for the subsequent campaigns. Intensive researches carried out during the winter and spring of 1915-1916 provided those satisfactory methods for filling and detonating H.E. shell, which enabled the Ministry's new supply organisation to turn out safe and efficient ammunition for the summer campaign. Similar action produced simple patterns for trench mortar ammunition, making it possible to supply this type of munition in large quantities for the battle period of 1916. The study of methods for improving munition design thenceforward progressed steadily along lines which will be denoted in the following chapter.

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[1] *Annual Report of the President, Ordnance Board,* 1915, p. XVII.

[2] HIST.REC./H./800/1, p. 4.

[3] See below, pp. 98-105.

CHAPTER V.

CONTROL OF DESIGN BY THE SUPPLY AUTHORITY, 1916-1918.

I. The Administration of Research and Design.

(*a*) THE MACHINERY FOR RESEARCH AND DESIGN.

The Design Department of the Ministry, which was thus established in December, 1915, was responsible for the patterns and specifications of all artillery material, rifles, machine guns and small arms ammunition, trench mortars, and trench warfare appliances. From March, 1916, onwards, the Director-General of Munitions Design ranked as military adviser to the Minister. He was responsible for the standards only of inspection, although he still depended upon the technical officers of the Inspection Department for such work as the drawing up of specifications and the reproduction of drawings. Manufacture of experimental stores and the actual preparation of drawings remained, as before, with the Ordnance Factories, Woolwich.

Steps were, however, taken to strengthen the experimental machinery both of the Ordnance Factories and the Research Department. Many of the delays in regard to design were attributed to the slowness with which experimental manufacture had proceeded and to delays arising from the passing of trial ammunition backwards and forwards for comparatively slight modifications. The need for sacrificing some of the bulk output from the Ordnance Factories in order to facilitate research on points of vital importance was becoming more and more apparent.[1] Moreover, by this date the proportion between the output from Woolwich and from other sources was diminishing, and the issues from the Ordnance Factories were about to be entirely eclipsed by the production of the new national factories. A Superintendent of Design was appointed to watch the interests of experimental work within the Ordnance Factory and to control the three departmental drawing offices. In two of these, the Gun and Carriage Factory Offices, the Superintendent of the Factory remained responsible for design, himself initiating gun designs. In the third factory, the Royal Laboratory, the Superintendent retained no responsibility for design, and the drawing office, which dealt with both small arms ammunition and shell filling, was staffed by nominees of the Superintendent of Design. It was considered desirable that the designing officers should remain in close touch with practical conditions in the factories. Hence, a proposal to centralise the drawing offices in London within the Department of Munitions Design was abandoned. The staff of the Research Department was also increased and its facilities for experimental manufacture were augmented. In particular, the Chemical

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[1] D.D.G.(C)/C.M.G./329/2.

Branch, which dealt mainly with matters touching explosives, was increased from 12 to 21 at the end of November, 1915, and additions were made to the numbers engaged upon this side of the work from time to time during the remaining years of the war.[1]

The duties of the officers of the Munitions Design Department resembled closely those which had been performed by the officers of the Directorate of Artillery. The department was intended to constitute an impartial tribunal, acting with full knowledge of all the conditions to be met, but refraining from direct intervention in developing or modifying patterns, since it is a well-known fact that few men are capable of discrimination where their own inventions are concerned. Accordingly, its main duty was to pass sentence upon suggestions placed before it. It was divided into two main sections along lines somewhat similar to the organisation of the Directorate of Artillery. Questions relating to the design of guns and gun ammunition, trench mortars and their ammunition fell within the province of Deputy Director-General (O), Lieut.-Col. J. Byron, R.A.; those relating to small arms and machine guns with their ammunition, grenades and other trench warfare appliances and optical munitions were allocated to Deputy Director-General (S), Lieut.-Col. F. J. Byrne.[2] Both in organising his department and in reconstituting the Ordnance Board as the Ordnance Committee, General Du Cane experienced great difficulty in obtaining personnel with the necessary qualifications. This he ascribed partly to the unwillingness of the War Office to release technical officers, partly to the extreme paucity of artillery officers who had had sufficient experience both in regard to technique and manufacture.[3]

In organising the Ordnance Committee, arrangements were made to appoint a chairman (Brig.-General W. St. C. Bland) and other officers who had had actual and recent experience in the field. The Admiralty representatives remained, with certain changes in personnel, and the committee continued to advise the Director of Naval Ordnance on naval matters as well as the Director-General of Munitions Design on military matters. It proved impossible to find an eminent mechanical engineer who was able to give full time to the work of the committee. Hence the associate members, who were intended to inform the committee on questions relating to production were, as before, better acquainted with the theory, than the practice, of manufacture. Weekly meetings of the committee were, however, held in London under the presidency of the Director-General of Munitions Design in order to enable the chief supply officers of the Ministry to be present in the interests of output, whilst the retention of the committee's headquarters at Woolwich enabled it to keep in close touch with the manufacturing problems at the Arsenal. The committee remained a purely advisory body,

[1] In November, 1915, there were 21 members of the staff organised in 6 sections; in February, 1917, there were 40 in 10 sections; in April, 1918, 91 in 15 sections; at the Armistice there was a staff of 106. (Information received from Research Department, Woolwich.)

[2] HIST.REC./H/800/1. [3] *Ibid.*

although it had been suggested by the Master-General of Ordnance that it should become an executive authority responsible for the initiation of research and the performance of experiments and also for the ultimate decision in regard to design.[1]

Similarly, the consideration of questions relating to the pattern of small arms, and their ammunition, grenades and other trench warfare appliances and optical munitions was concentrated within a committee, known as the Munitions Design Committee, which was responsible for giving definite recommendations for the final decision of the Director-General of Munitions Design.[2] The committee acted in sections dealing respectively with small arms and trench warfare supplies. Meetings of the Small Arms Section were occasionally attended by a naval representative. The chairman of the section was the Chief Inspector of Small Arms and trials were still executed by the experimental officer of the School of Musketry, and the administration of the experimental establishment at Hythe was transferred to the Ministry.[3] The procedure in regard to the design of these weapons was accordingly very little altered by reason of the transfer of authority to the Ministry.

Trench warfare and chemical warfare stores, however, lost part of their distinct treatment, when the Design Department was completely organised in March, 1916. Between the time of the Ministry's formation in June, 1915, and the end of that year, responsibility for initiating and conducting research as to these two classes of stores, for approving the patterns and supplying in bulk, had all been concentrated under a single control within the Ministry. In December, 1915, the supply authority was divorced from this control on the ground that the subordination of supply considerations to those of design were involving unnecessary delays in production. The design authority (Brig.-General L. Jackson) continued his responsibility for researches, but lost the power of decision as to the final pattern with the establishment of the Munitions Design Department in December, 1915.[4] It was decided about the following March that the Trench Warfare Research Department, together with its experimental grounds and drawing offices, should be brought under the control of the Director-General of Munitions Design.

The absorption of trench warfare research into the Department of Munitions Design had the result of concentrating within one military department the entire responsibility for the quality of the stores supplied by the Ministry.[5] The position of the Director-General of Munitions Design as military adviser to the Minister was then formally recognised; but his power in regard to inspection was still limited to the final decision in regard to specifications, while the administrative work of testing stores was placed under a civilian

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[1] 1/Gen. No./1608.
[2] D.G.M.D./Gen./8.
[3] War Office Memorandum, No. 833, 16 March, 1916 (Hist.Rec./R/200/2).
[4] Vol. XI, Part I, pp. 8–10.
[5] C.R. 4470; Hist.Rec./H/800/1.

head.[1] The independence of the Munitions Inventions Department was also maintained, chiefly for personal reasons.

The concentration of design duties in a single department of the Ministry was in accordance with the lines of its general organisation, which tended to divide into watertight compartments its various functions towards stores, such as manufacture, filling, the financing of production,[2] rather than to follow the usage of the War Office in subdividing the Department according to the use and nature of the equipment. The chief object of so centralising the responsibility for design was to lessen the risk that manufacturing considerations should predominate unduly over military requirement in a purely civilian department.[3] One of the main disadvantages of this system was the consequent difficulty of securing a sufficiently close relation between the officers responsible for design and supply.[4]

It must, however, be noted here that the concentration of responsibility for design was not complete. It was maintained in the case of standard stores, artillery material, small arms and their ammunition. Its application to trench warfare stores was only temporary.[5] It was never extended to certain new, or comparatively new, munitions, such as tanks and aircraft, nor to important classes of war material, such as motor transport, the supply of which was transferred to the Ministry from the Department of the Quartermaster-General and not from that of the Master-General of Ordnance. The project for including inspection and inventions under the same control as design was in part fulfilled in August, 1917. The Design Group of the Munitions Council, which was then formed, included the Munitions Design Department and also departments dealing with inspection, inventions and trench warfare research. Major-General the Hon. (later Sir) F. R. Bingham, who had succeeded General Du Cane as Director-General of Munitions Design in September, 1916, became Council Member for Design in control of these four departments. Even this grouping of units concerned with the quality of munitions was not permanent nor complete. The departments dealing with inventions and trench warfare design were included, in July, 1918, in a new Council Group, called "Warfare," for reasons which were mainly personal.

The machinery adopted by the Design Department of the Ministry thus followed the general practice of the War Office in regard to research, while developing the staff and facilities formerly provided for the purpose. The organisation of the Ministry in regard to research generally was established upon a much broader basis. The mobilisation of the country's scientific knowledge for the production of warlike stores had already been partially effected in June, 1915, by the formation of the Ministry from a body of industrial experts well acquainted with the manufacturing aspects of the problem. At the same time, special technical advisers on particular subjects were

[1] See above, p. 42.
[2] Colonel Lee, 18.4.16 (C.R. 4470).
[3] HIST.REC./H/800/1, p. 6.
[4] See below, p. 93.
[5] See below, p. 63.

appointed to the various supply branches. Thus, for example, Dr. (later Sir) R. T. Glazebrook, of the National Physical Laboratory, became the consultant to the Ministry upon physical matters,[1] and Professor F. J. Cheshire joined the Ministry as a technical expert on optical matters, while Mr. W. R. Lysaght and Professor F. W. Harbord advised the Department on various metallurgical questions.[2] The Explosives Supply Department had already led the way in this respect from the previous December, when technical experts acquainted with the manufacture and properties of explosives and their materials had been added to its staff.[3]

The starting up of the new national factories during the winter and spring of 1915–1916 provided an entirely new source of knowledge, which in some respects, as, for example, in the filling of high explosive shell, eventually outgrew the experience of the older Ordnance Factories. Systematic investigations were pursued in the factory workshops and in special laboratories attached to them, as, for instance, at the National Filling Factory, Chilwell, or H.M. Explosives Factory, Oldbury. Various sections of the Ministry also established and controlled special experimental grounds or workshops for particular purposes. A list of these will be found in Appendix IV, below. They were extremely diverse in character and employed staff in various numbers, ranging from the 14 employed at the Dollis Hill Tank Experimental Ground to the 1,274 employed at the Research Department (with Proof Butts), Woolwich.[4] In addition, numerous problems in connection with warlike stores were referred to scientific and learned bodies or to individual experts, who carried out investigations in their own laboratories and workshops, or formed advisory bodies attached to different departments. The knowledge and equipment of the Universities were utilised in many directions, as well in respect to the evolution of new equipment as in the development of process, the study of methods of testing and investigations as to the causes and remedies of industrial disease.[5] It would be quite impracticable so much as to name the individual persons or bodies who were engaged upon such researches on behalf of the Ministry. In many instances individual firms undertook a special line of research, and equipment for the purpose was provided at State expense. A vast amount of knowledge of an extremely technical nature and of great diversity was thus obtained. One of the chief administrative difficulties experienced by the Ministry was that of correlating the results of these investigations with the concurrent advances made in military science, a problem which is discussed later.[6]

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[1] Particularly in respect to the testing of gauges (see Vol. VIII, Part III, pp. 32–34).

[2] See Vol. XI, Part III, p. 1.

[3] See Vol. X, Part IV, p. 36.

[4] Estab. Cent. 1/281.

[5] There was also a special section of the Labour Regulation Department, which was engaged upon matters affecting the welfare and health of munition workers (Estab. Cent. 1/281).

[6] See below, p. 99.

(b) Treatment of Inventions and Novel Stores.

A systematic use of the brains of the country was most essential in the development of novel stores. The Munitions Inventions Department was an important part of the Ministry's machinery for this purpose.[1] Its primary duty was to examine proposals from every source with a view to ensuring their adoption and development if they were likely to be of service to the State in carrying on land warfare. A very large proportion of the suggestions received were impracticable, had already been exhaustively treated, or were unsuitable for existing conditions. From August, 1915, till the end of March, 1919, nearly 48,000 inventions and ideas were received, and about one-twelfth of this number were considered worthy of detailed investigation. Of these rather more than 200 were eventually adopted for service or approved for extensive field trials,[2] while a large mass of information was obtained in the course of the remaining investigations.

From the consideration of subjects submitted, it was a short step to conducting and even initiating researches on various questions. The department had special facilities for this purpose in its drawing office, its workshop for models and in the experimental grounds which it controlled.[3] It became responsible for initiating research in connection with mechanical, chemical and engineering subjects, such as the utilisation of waste products or the fixation of atmospheric nitrogen. It investigated the means of dealing with aircraft attack, the location of aircraft and improvements in anti-aircraft gunnery. It worked through a panel of some fifty expert advisers working in committees and sub-committees, and a headquarters staff of specially selected examiners.

The somewhat anomalous position which the department had occupied owing to the retention of an inventions branch by the War Office was improved at the end of 1915, when the Ministry became responsible for design. The decision taken in November, 1915, included the acquisition by the Ministry of responsibility for examining warlike inventions,[4] and the staff of the War Office Inventions Branch was accordingly transferred to the Munitions Inventions Department.[5] The most notable increase thus made in the Minister's responsibility towards inventions related to patents, royalties and rewards. Already in July, 1915, he had been empowered to authorise contractors to use registered designs without the consent of the registered proprietor,[6] and in October, 1915, the Army Council notified its formal authority for the extension to the Ministry of Section 30 (12) of the Patents and Designs Act, 1907, with a view to preventing the communication of any invention relating to munitions of war from prejudicing the inventor's subsequent application for a patent. This authority was,

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[1] For a detailed account of the department's work see Hist./Rec./H./700/2.

[2] For some particulars of these, see below, p. 66.

[3] For a list of these see Appendix IV.

[4] M.W. 1374/12.

[5] C.R.V./Gen./30.

[6] See Vol. II, Part I, Chap. VII.

however, restricted to inventions communicated directly to the Ministry, while the inventor's consent was thenceforward to be obtained before inventions submitted to the War Office were to be referred to the Ministry.[1] After the transfer of responsibility for designs and inventions it was arranged (March, 1916), that applications to take out patents which were made by officers and men, or by officials of the War Department, should be examined by the Munitions Inventions Department and submitted to the Director of Artillery; that secret patents should be dealt with by the department, subject to the approval of the Director of Artillery or the Comptroller of Munitions Inventions, as the case might be; and that matters relating to royalties and rewards should be investigated and negotiated by the Munitions Inventions Department on behalf of the War Department, the decision as to amounts to be paid or financial adjustments resting with the War Office finance officers; and that certain officers of the Ministry should be appointed by the Army Council to advise the Comptroller of Patents in regard to suspending the publication of patents under Defence of the Realm Regulation 18(B).[2] Still more drastic powers were taken by the Ministry in conjunction with other Departments in September, 1916, when authority was taken to insist upon the disclosure of inventions or secret processes with a view to the more efficient or increased production of war material. The use of this regulation was extremely limited.[3] The willingness of trade bodies to reveal their secrets increased with the general growth of co-operation among makers of munitions.[4] It was only in exceptional instances, that the development of production was seriously hampered by an inventor's unwillingness to communicate information, as, for instance, had been the case in the evolution of the earlier types of grenades.[5]

After the transfer of the Inventions Branch of the War Office to the Munitions Inventions Department, this department became concerned with stores supplied by the Quartermaster-General and the Department of Fortification and Works, and its activities thus covered a far wider range of stores than those supplied by the Ministry. It did not, however, obtain that close touch with conditions in the field which would have enabled it to fulfil the duty, originally defined by Mr. Balfour,[6] of formulating military needs for the benefit of the civilian inventor.[7] Its activities were, moreover, restricted by the claims of the Munitions Design Department to consider all questions relating to large and important classes of stores of a comparatively standardised nature. There thus lay between the two departments an uncertain zone whose boundaries were the constantly shifting lines between invention on the one side and the modification of pattern on the other. This difficulty of demarcation was enhanced by the comparatively independent position of the Inventions Department,[8] and it was not until September, 1918, that a complete system of co-ordination between the

[1] M.W. 1000/4; 84/Gen. No./4503.
[2] 1/Gen. No./1639.
[3] See Vol. II, Part I, Chap. VII.
[4] See Vol. VIII, Part IV, Chap. II.
[5] Vol. XI, Part I, pp. 74–75.
[6] See above, p. 48.
[7] Hist.Rec./H./700/2, p. 14; A.C. 65.
[8] A.C. 65.

departments concerned with invention, research and design was finally established.[1]

The development of certain classes of novel munitions was still treated along special lines, in conformity with previous practice, and with but little reference to the centralised Design and Inventions Departments. In October, 1917, the Trench Warfare Research Branch of the Design Department ceased to exist, and its duties in regard to investigating trench warfare munitions were transferred to a new Trench Warfare (Design) Department, consisting largely of officers with recent experience in the field and strengthened by an advisory committee upon which supply officers were *ex-officio* members. In the following August this department was entrusted with very wide authorities in regard to research, with a view to providing new stores; but its activities in this direction had scarcely developed before the close of hostilities.[2] The extremely technical and entirely unprecedented nature of gas warfare added very special difficulties to the administrative problems involved in developing and applying chemicals for military use. During the years 1916-1917, experimental work was much advanced by the establishment of a large scale experimental ground, and some degree of correlation with anti-gas authorities was attained through officers appointed to study defensive measures there in May, 1917. In the following November the duties of the Trench Warfare Research Branch in regard to offensive substances and the responsibilities formerly exercised by the War Office in respect to the design and supply of defensive apparatus were concentrated under a Controller of Chemical Warfare, to whom was transferred the power of sentencing design. The Design Department of the Ministry retained the duty of passing sentence on the patterns of chemical projectiles only.[3]

An entirely different procedure was adopted in the case of tanks, for which the Ministry became responsible in February, 1916, and in regard to aircraft. The development of the first tank was a notable instance of success attending the concentration of a few experts upon a problem, which they investigated under practical workshop conditions as well as round the council table. No real advance was thereafter made until close touch had been attained with actual conditions in the field. In fact, one of the earliest difficulties experienced was to obtain any definite formulation of the conditions to be met by the new war machine. When these had eventually been defined, mainly through the activities of a single individual, Lieut.-Colonel E. D. Swinton, the form of the pattern, or "mother" tank, was rapidly evolved by a technical officer and an expert manufacturer working together in the latter's factory under the guidance of the chief naval design officer. This method of treating a new and complex problem in a positive way compared very favourably with the comparatively negative treatment by trial and error, the results of which had already caused a similar project to be abandoned by military design authorities.[4]

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[1] General Memorandum, No. 121 (14.9.18).
[2] Vol. XI, Part I, pp. 10–13; see below, p. 101.
[3] Vol. XI, Part II, Chap. II.
[4] See Vol. XII, Part III, Chaps. I and II.

Experimental work upon the tank was among the chief investigations as to land warfare which the Admiralty undertook to transfer to the Ministry of Munitions in the summer of 1915. In order to ensure continuity of work, it was subsequently agreed to leave the development of the experimental machine with the Admiralty committee, which had been established by the First Lord in the previous spring. When the supply of the new machine was eventually undertaken by the Ministry in February, 1916, the members of this committee remained as advisers on design. Actual research and experiment was carried out by several distinct authorities, but the responsibility for this work lay primarily with the supply department, and an attempt to centralise experimental work in this department, which also controlled inspection, was successful in October, 1917. The department had its own technical officers, and carried out investigations at two experimental grounds.[1] Its administrative history is one of continuous struggle to retain full authority over design as well as supply.[2]

It was not until March, 1917, that the Ministry of Munitions became responsible for aircraft production ; but from a technical point of view aerial warfare was still at an experimental stage. Some aeronautical inventions had previously been dealt with by the Munitions Inventions Department on behalf of the Directorate of Military Aeronautics, which included a section responsible for both the design and the supply of aviation material and controlled experimental work at Farnborough. The Admiralty had maintained a separate technical department for aeronautical stores and design officers, who were responsible for new types of machine and also for controlling the production of experimental stores.[3] This department had its own drawing office, but its work was seriously hampered by lack of facilities for experimental construction. In July, 1916, the work of the Munitions Inventions Department in respect to military aircraft had been transferred to the newly established Air Inventions Committee.[4] The responsibility for supply, which was transferred to the Ministry in March, 1917, did not include any control over design activities, and the Air Board had its own technical section and experimental grounds and also administered the arrangements for flight tests, from which much knowledge as to the development of machines was gained. The technical section was, however, transferred to the supply authority upon the formation of the Air Ministry in May, 1918,[5] and throughout the period of the Ministry's control peculiarly close contact was maintained with the actual users of the machines supplied.[6] The success attained by these methods of design was very remarkable, and is clearly illustrated by the advances made in the general efficiency of aircraft, which are scheduled in Appendix VI.

II. Achievements in Regard to Design.

In spite of the great difficulty which attended any attempt to change the nature of munitions of war pending hostilities, the advances which

[1] Vol. XII, Part III, Chaps. III and IV.
[2] See below, p. 104.
[3] Vol. XII, Part I, Chap. II.
[4] A.B. 400/14 ; Estab. W.P. 5/12.
[5] Vol. XII, Part I, Chap. III.
[6] See below, p. 105.

were made between 1916 and 1918 were very remarkable. A great deal was done in the direction of improving the efficiency of stores, in simplifying patterns in order to facilitate production, in adapting designs to meet the exigencies of the time, and in inventing new weapons.

(a) IMPROVEMENTS IN PATTERN.

Numerous improvements were effected in standard munitions to meet experience gained in the field. It would be impracticable to describe these in detail. Some of the most noteworthy were changes which were made in the pattern of guns and howitzers with a view to increasing range and improving the firing mechanism and the recuperator and recoil systems. Increased range was obtained partly by changes in the gun, partly by modifications in the shape of the shell. Among the most remarkable results thus attained were the increase of the 18-pdr. range by about 3,000 yds., and of the 60-pdr. range by some 4,500 yds.[1]

Anti-aircraft artillery was the subject of continuous advances, the anti-aircraft armament on high angle mountings of 1914 would fire two miles; by the end of the war, British anti-aircraft artillery could fire effectively at aeroplanes flying five miles up. The simultaneous development of height-finding instruments and other apparatus was even more remarkable.[2]

The main improvements in regard to gun ammunition concerned the development of high explosive shell. The problem of detonating new and comparatively insensitive explosives had seemed in 1915 to be almost beyond the possibility of solution within the period of the war. By the end of 1917, this difficulty had been successfully overcome and the high quality of the new types of high explosive shell had been assured.[3]

Little improvement to the design of the rifle was needed; but considerable advances were made in the development of small arms ammunition for special purposes, and designs of tracer, incendiary, and armour-piercing bullets were developed or improved during the years 1916 and 1917.[4]

(b) SIMPLIFICATIONS IN DESIGN.

The simplification of designs with a view to expediting production received continual study. An early step was taken in this direction in the spring of 1916, when new and simple fuses were introduced which enabled trench mortar ammunition to be provided in large quantities without encroachment on the capacity for artillery *matériel*.[5] Concentrated study by the technical section of the Gun Ammunition Filling Department led to the elimination of many unnecessary items among the numerous minor components which went towards the production of a complete round.[6] In September, 1917, after more than

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[1] See Vol. X, Part I, Chap. IV.
[2] See Vol. X, Part VI. Chap. I.
[3] See Vol. X, Part IV, p. 20.
[4] See Vol. XI, Part VI, Chap. II.
[5] See Vol. XI Part I, pp. 52–4.
[6] See Vol. X, Part V, Chap. V.

a year's investigation, the standardisation of shrapnel components was approved, so that it became possible to manufacture tubes, sockets and wood-filling centrally and to issue them to contractors.[1]

(c) Adaptation of Design to the Available Resources.

As the stringency of the economic position increased, numerous expedients were adopted for the saving of material or for economising money. The first recommendations made by the Metals and Materials Economy Committee in December, 1916, involved a saving of nearly 60,000 tons of copper from such changes in pattern as the narrowing of the driving band on the shell.[2] Much investigation finally resulted in the development of many patterns (*e.g.*, aerial bombs) in cast-iron instead of brass or steel. These included cast-iron fuses, the development of which needed great care owing to the high stresses to which they were subjected in the gun and because of the great difficulty of making so delicate an article in cast-iron and the need for providing some means of protection against rust.[3] Remarkable changes in the nature of high explosive ammunition were also made with a similar object, so that, in the end, the kind of explosives used could be provided with the least possible dependence upon materials from overseas and at a minimum of cost.[4]

(d) Inventions.

The development of new stores to meet new conditions of warfare was among the most striking features of munition supply. The main patterns of trench warfare apparatus had been developed by the spring of 1916. Some forms of cloud gas and lachrymatory shell had also been evolved by then; but the great bulk of the work of designing lethal artillery shell was effected from May, 1916, onwards, and the Livens projector introduced an entirely new means of producing cloud gas during the spring of 1917. The initial pattern of the tank had been developed during the last six months of 1915; but numerous improvements were effected before the close of the hostilities by which time the new engine of war had also been adapted to serve a multifarity of purposes.

The Munitions Inventions Department aided the introduction into service of large numbers of miscellaneous articles and apparatus. Among the more important of these were the mirror position finder for locating the position of the burst of a shell and sound locators, which were successfully used in anti-aircraft defence. A great deal of the work of this department concerned manufacturing processes, and included such investigations as the development of a large scale method of utilising atmospheric nitrogen. Others of its activities lay without the scope of the Ministry's supply work, and dealt with

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[1] (Printed) *Weekly Report*, No. 44, XII (3/6/16); No. 107, XII (1/9/17).
[2] Hist.Rec./R/1800/41.
[3] See Vol. X, Part V, Chap. V.
[4] See Vol. X, Part IV, p. 21.

researches upon a diversity of matters, as, for instance, the best methods for manufacturing artificial limbs.[1]

It is not possible or desirable to attempt any definition of the Ministry's responsibility for the great advances which were made in regard to the design of munitions generally. They were the result of concentrated and determined investigation on the part of numerous individuals, firms and departments, whose efforts resulted not only in the concrete improvements already indicated but also in the accumulation of a mass of knowledge on abstruse and technical subjects for future use, both military and civilian.

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[1] Hist.Rec./H/700/2.

CHAPTER VI.

ADMINISTRATION OF INSPECTION BY THE MINISTRY OF MUNITIONS, 1916–1918.

I. Growth of the Work of Inspection, 1916–1918.

From April, 1916, onwards the accelerated rate of production in all branches of munitions threw more and more work upon the authorities responsible for inspection, and the introduction of new patterns and frequent changes in design also made heavy demands upon the Inspection Department. During this period the salvage and repair work of the inspecting officers developed to a hitherto unknown extent, and, most important of all, the Inspection Department extended its organisation to undertake many new duties, notably the inspection of steel and of mechanical transport vehicles. Yet, in spite of unforeseen conditions and the immense difficulty of securing adequately trained officials in sufficient numbers, the Inspection Department succeeded not merely in keeping pace with the rate of production, but actually maintained a standard of inspection which was considerably higher than that enforced in any Allied country. "Considering the vast quantity of munitions sent overseas,"[1] said the Director-General of Inspection in December, 1918, "the complaints arising through defective inspection, all of which came before me, have been quite extraordinarily few in number, and this fact alone is a source of great satisfaction considering the vast number of new designs and devices which have been manufactured in large quantities without any previous experience of their performance."

Before considering the new responsibilities for inspection assumed by the Ministry of Munitions, it will be well to trace briefly the growth of the work in the existing divisions.

(*a*) Guns.

The great increase in the issue of guns, which was one of the features of munition production in 1915, was continued in the following year. In July, 1916, in view of the imperative need for an immediate output of the heavier natures, the Inspection Department agreed to expedite inspection by temporarily omitting some of the less important tests after proof. At the same time, arrangements were made to provide extra staff accommodation and a connecting officer was appointed between the supply and inspection departments as well as between the two inspection divisions concerned.[2]

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[1] Conference, December, 1918 (Mr. Collinson's Papers No. 2).
[2] (Printed) *Weekly Report* No. 46, XIII (17/6/16).

As the war continued, the work of testing guns which had been returned from overseas increased enormously, and by July, 1917, had reached such proportions that the inspection shops at Woolwich were hopelessly overcrowded. To relieve this congestion, arrangements were made in November, 1917, to transfer this work to the factories to which the guns were sent for repairs, and, as soon as the National Ordnance Factories at Leeds and Nottingham were in full working order, not only was the pressure at the Arsenal relieved, but the time taken in repairing worn-out guns and returning them in serviceable condition to the Army was materially reduced. In April, 1918, it was estimated that in the case of 18-pdr. guns repaired at the National Ordnance Factory, Leeds, the average time, from the date of arrival at a home port till the date of re-issue, was 46 days, of which 10 were spent in inspection, including proof and adjustments.[1]

During the period April, 1916 to November, 1918, ten new gun factories were established, and great difficulty was found in providing a sufficient number of efficient assistant inspectors, until the problem was solved by employing Royal Artillery officers, as experience proved that expert Royal Artillery officers trained much more quickly as assistant inspectors than the average civil engineer, since they started with a fairly thorough knowledge of the essential qualities of a good gun.[2]

In July, 1917, the great increase in the production of grenades and of trench mortars with their ammunition made it desirable to subdivide the work of the Director of Guns and Grenades. A new directorate under the control of a Director of Inspection of Trench Warfare was appointed. The portion of the staff of the Director of Inspection of Guns and Grenades which had hitherto dealt with trench warfare stores, was transferred to the new directorate[3] which was shortly afterwards housed with the corresponding supply department, whilst it still reported to the central inspection authority of the Ministry.

(*b*) CARRIAGES.

The great extension in the issue of guns during this period caused a corresponding development in the work of the Carriages Division, which was further increased by the introduction of tanks into modern warfare and the extended use of guns on railway mountings. In addition to these developments, further claims were made upon the inspection officials by the establishment of repair shops at Southampton where carriages returned from overseas were inspected and overhauled, the extent of the damage estimated, and the carriages sent, in case of extensive repairs, to the armament firms or retained at Southampton for treatment where the injuries were of a minor character.

The work of the Inspection Branch increased so rapidly, that, in August, 1916, it was decided to relieve the Carriages Division of

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[1] (Printed) *Weekly Report*, No. 139, II (27/4/18).
[2] HIST.REC./H./900/3b. p. 3.
[3] (Printed) *Weekly Report*, No. 102, XIII (28/7/17).

the inspection of all wooden articles, such as boxes, cases and chests which they had hitherto carried out and transfer it to the divisions concerned with the stores for which these cases were intended. This change had the dual advantage of relieving the division from inspection duties in no way connected with military carriages, while at the same time giving the other divisions fuller knowledge of the arrangement of their stores.[1]

In the Carriages Division, the functions of the Supply and Inspection Branches tended to overlap, and the Director-General of Inspection complained of the loss of time caused by the fact that in cases where material in bulk had been supplied to the carriage manufacturers in error, condemnation by the inspection authorities was not regarded as sufficient, but the material had to be returned and re-tested by the department from whom it had been supplied.[2] Great vigilance was necessary on the part of the inspection officers to check wastage of material. Very accurate forging was necessary in many of the components making up a military carriage and the manufacturers, in their efforts to secure as large an output as possible, wasted very large quantities of materials by persistently forging much too near the critical point.[3]

(c) Small Arms.

The inspection of small arms, both on the technical side and also for larger questions of administration, was controlled by the Deputy Director-General. Inspection was mainly carried out at Enfield Lock, Birmingham and Slades Green, and the officials had great difficulty in co-ordinating the rifles and machine guns produced in the London area with those from Birmingham, owing to different manufacturing methods and differences in gauging.[4]

The pressure upon the Small Arms Branch was not as severe as in many of the other divisions and the only new duties the inspection officers were called upon to undertake, from the formation of the Ministry until the close of the war, were supervision of the establishment at Slades Green to deal with machine guns made at Erith and Crayford, and the inspection of Hotchkiss machine guns at Coventry, Lewis gun magazines at Nottingham, bicycle tyres at Birmingham, and machine gun belt boxes and machine gun tripods manufactured at various places.[5] During this period (1916–1918), the manufacture of machine guns increased much more rapidly than the home production of rifles and any additions to the inspection staff were made to facilitate the examination of machine guns. Great care was taken to maintain close relations with the Design Branch, and Colonel G. H. S. Browne acted in a dual capacity as Assistant Controller of both the inspection and the design of machine guns.[6]

(d) Small Arms Ammunition.

The combing out of men of military age in November, 1916, greatly depleted the inspection staff in the Small Arms Ammunition

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1 Hist.Rec./H./900/8.
2 Mr. Collinson's Papers, No. 2.
3 Mr. Collinson's Papers, No. 2.
4 Hist.Rec./H./900/12, p. 18.
5 Hist.Rec./H./900/12, p. 7.
6 Mr. Collinson's Papers, No. 2.

Division and as far as possible their services were replaced by the introduction of women into the signal light and box shops at Park Royal, the re-examination and box shops at Plumstead Marshes and in the Arsenal. The transference of the inspection of small arms ammunition boxes from the Carriages Division in August, 1916, threw additional work upon the division and extra accommodation had to be provided at Woolwich Arsenal, Plumstead and Park Royal. In the spring of 1918, the shortage of supplies of wood suitable for boxes for packing ·303-in. ammunition became acute, and as the best solution of the question, the Director of the Small Arms Ammunition Division decided to relax the specifications laid down for inspection and allowed manufacturers to use soft wood ends.[1]

(*e*) SHELL AND COMPONENTS.

During this period, the time occupied in the inspection of empty shell was greatly reduced, partly by improved methods in manufacture and partly by better methods of inspection. In the larger natures of shell, great improvement was made by the introduction of labour-saving devices, such as rolling benches and the suspension of cylindrical gauges, which avoided loss of time in moving heavy shells and gauges and also made it possible for women to be employed in the inspection of large shell.

The following table, which shows the rate per examiner per hour, illustrates the marked improvement in the rate of shell inspection which occurred between July, 1916 and October, 1917.[2]

	Rate per examiner per hour.	
	July, 1916.	*October*, 1917.
12-in.	2	2½
9·2-in.	2½	4¾
8-in.	3	5¼
6-in.	5½	7
60-pdr. H.E.	6¼	8¾
60-pdr. Shrapnel	6¼	11
18-pdr.	8¾	12¼
3-in. Shrapnel	10¼	25

Important changes were made in regard to the inspection of minor components during the autumn of 1916. Until then, this work had been undertaken for the new filling factories by the Filling Department of the Ministry just as it had been customary for the Royal Laboratory to test the quality of the components used in completing gun ammunition there. In the autumn and winter of 1916, special steps were taken to tighten up the inspection of components generally as a means of improving the quality of gun ammunition,[3] and on 20 September, 1916, it was decided that this work should be transferred from the supply officers to the Director of Inspection of Gun Ammunition (Supervisory) and to the Director of Inspection of Munition Areas. The existing staff and buildings at Dudley and at Birmingham, so far as they were concerned with inspection, were transferred to the Director of Inspection of Munition Areas, and the new inspection

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[1] (Printed) *Weekly Report*, No. 138, II (20/4/18).
[2] (Printed) *Weekly Report*, No. 130, II (16/2/18).
[3] See Vol. X, Part V, Chap. IV.

authority made use of facilities which already existed in the Supply Department's technical shops at Perivale for inspecting fuse components and certain small parts of shell, and of facilities at Wandsworth for testing the large components of shell. Gauges designed by the Inspection Department for the inspection of components were to be gradually substituted for those in current use.

(f) Propellants.

The main development in regard to the inspection of propellants arose from the increase in the number of proof butts.[1] The need for suitable assistants was thereby greatly increased.

The number of examiners employed in the department was small, as stability and ballistic tests were carried out by organisations not under its control, but the technical nature of the work and the comparatively small number of firms engaged in the production of propellants, made it almost impossible to obtain assistants with any previous experience for the inspection staff.

(g) High Explosives.

The success of the experiment,[2] by which the Universities took over the local inspection of all high explosive supplies in their neighbourhood, was unqualified. Without this assistance, the Inspection Department would have found great difficulty in performing the work satisfactorily and would have been involved in serious trouble in regard to transport. A report upon the work of the Universities at the end of 1917, may be quoted[3] :—

> "The deputy-inspectors in charge and their staffs are deserving of the greatest praise and have performed work of the highest national importance.
>
> The deputy-inspectors gave their services entirely free for eighteen months and are now only in receipt of a nominal honorarium of £300 per annum to compensate them in some measure for the loss of income from other sources through expenditure of time on inspection work.
>
> That staffs and expenses have been kept to a minimum is well shown by the percentage costs tabulated below. Indeed, it is remarkable that the work has been carried out at such a trifling cost without a single serious complaint having been substantiated or even made against the inspection.
>
> The greater part of the apparatus used and all the laboratories have been placed free at the service of the country by the University authorities. Had it not been for this service, great expense in establishing and equipping laboratories would have been necessitated. It should also be remembered that the Universities have done considerable work for other branches of the Inspection and Explosives Departments such as analyses of steel, paint, varnish, tar, etc."

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[1] See below p. 82. [2] See above, p. 34.
[3] (Printed) *Weekly Report*, No. 124, II (5/1/18).

II. Developments in the Administrative Organisation, 1916–1918.

(a) DECENTRALISATION.

The reorganisation of the headquarters staff of the newly established Inspection Department in March, 1916, under a Director-General with four Deputy Directors-General, was the first of a number of administrative changes. With the great increase in the work of inspection, the centralisation of responsibility for administration and organisation in the person of the Chief Inspector, Woolwich, became no longer practicable. Wider powers were necessarily given to the officers in charge of the various sections, and many of the responsibilities which had hitherto rested with the Chief Inspector, Woolwich, were delegated to them.

As has been already seen,[1] the Chief Inspector, Woolwich, was transferred from Woolwich to the new headquarters in Whitehall Place and given the title of Deputy Director-General (Technical). In April, 1916, the Treasury sanctioned the reorganisation of the Inspection Department into nine main divisions concerned respectively with gun ammunition (supervision), gun ammunition (technical matters), carriages, guns and grenades, optical supplies, small arms ammunition, filling, inspection of munition areas, high explosives, and propellants.[2] The decentralisation of the department was now complete; the directors of the several divisions being given full power to decide, on their own responsibility, many matters relating to their sections which would previously have been dealt with by the Chief Inspector, Woolwich. The final organisation of the department as it was in November, 1918, is shown in Appendix III.

(b) CO-ORDINATION WITH SUPPLY AND DESIGN.

When the Ministry of Munitions came into existence and the duty of inspection of munitions was taken away from the War Office and put into the hands of the Ministry, an attempt was made to keep the Supply, Design and Inspection Branches as it were, in watertight compartments, with little co-ordination with one another. Experience showed, however, that closer relations between these branches, which were so closely dependent upon one another, had the most valuable results. "Design and Inspection must be absolutely married," said Major General Bingham in January, 1918.[3] "What is the use of my people producing a design if the inspection people come along and say 'No, it would be quite impossible to inspect that. It is very intricate and very clever, but we cannot inspect it to ensure its safety.'" So imperative was it that the Design and Inspection Branches should co-operate closely in arranging the discretionary limits, without which production

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[1] See p. 42.

[2] (Printed) *Weekly Report*, No. 39, XIV (29.4.16). The divisions were respectively controlled by Lieut.-Col. F. L. Galloway, Bt. Lieut.-Col. H. G. Howorth, Major F. M. Rickard, Major H. M. Vandaleur, Major A. C. Williams, Major C. R. B. Owen, Major G. B. Denne, Mr. A. H. Collinson, Major C. D. Crozier and Major F. D. Gethin.

[3] Conference of Inspection Departments, 15 January, 1918 (Mr. Collinson's Papers, No. 2).

was impossible, that in January, 1918, the Inspection Branch and the Design Branch were grouped together under one member of Council (Major-General the Hon. Francis Bingham).[1]

In the relations with the supply department, it was found that the advice and practical experience of inspection officials, in matters not strictly within the limits of their duties, had a valuable influence, not merely in raising the level of production but also in materially increasing output. Inspectors were often able to assist contractors both in regard to methods of manufacture and with advice in overcoming difficulties preliminary to government inspection, thus saving time, money and material. At first these efforts were looked upon in certain quarters as tending to undermine the responsibility of the supply department in its own work, but the results in practice proved so satisfactory that the relations between the two branches became much closer as the war continued. In the case of inspection bonds, owing to the fact that the arrangements were made in the first months of the Ministry before a separate Inspection Department was established, the functions of the two departments were never dissociated, and while all the personnel dealing with store keeping, traffic, receiving and delivery were on the strength of the supply department, they received their instructions from the inspection authorities.

(c) THE EFFECTS OF THE NATIONAL FACTORIES.

The development of national factories in the spring and summer of 1916 gave rise to special problems by bringing the conflicting interests of the supply and inspection authorities into sharper juxtaposition. The position was particularly acute in the case of the National Filling Factories. The supply authorities concerned maintained that labour and time would be economised and a higher standard of efficiency attained if the numerous but comparatively unskilled examiners of the Inspection Department, who were located at all National Filling Factories, could be replaced by a few highly expert officials.[2] In January, 1917, the Controller of Gun Ammunition Filling made a formal proposal that his officers should become responsible for the correct filling of the ammunition.[3]

This proposal was strongly opposed by the Director-General of Inspection of Munitions (Sir Sothern Holland) on the ground that the standard of quality was all-important, and that this could only be maintained by independent inspection. He further pointed out that the recent difficulties with prematures and defective shell had been the cause of the more stringent inspection which had led to Colonel Milman's protest,[4] and that in countries where the responsibility for good production rested with the factory managements, as for example in France, the standard of production was far below our own. The

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[1] For the measures taken to secure intimate co-operation between inspection, supply and design, see below p. 91.
[2] C.M. 4/3105.
[3] *Ibid.*
[4] *Ibid.*

Minister of Munitions (Dr. Addison) agreed with Sir Sothern Holland in rejecting the proposal to take from the Inspection Department a duty which he regarded as its proper responsibility.[1]

(*d*) THE PREPARATION AND ISSUE OF SEALED DRAWINGS.

With the formation of the Inspection Department and the reorganisation of the administrative work in the spring of 1916, changes were made in the procedure for issuing drawings, which it was believed would result in great saving of time between the approval and final sealings of the new designs, and also in the issue of necessary particulars to contractors. An information bureau, equipped with a complete set of drawings and a fairly complete set of patterns, was established at the Ministry's headquarters in April, 1916, and arrangements were made to instal a printing plant capable of reproducing the drawings required for the department. The new procedure worked well, and within a few weeks improvement was reported in the rate of dealing with drawings, particularly in the case of gun ammunition, as the result of the reorganisation.[2]

Many suggestions for modifying designs and specifications arose from the inspecting officers. In order to minimise the practical disadvantages and limitation of output arising from constant changes of design, instructions were issued in June, 1917, to the directors of the various divisions of the Inspection Department that all alterations suggested in their sections must be carefully scrutinised before submission to determine whether they were necessary, or desirable, on the ground of safety, increased efficiency or economy in production.[3] All changes were to be divided into two categories, extremely urgent and less urgent, and in the second category the principle was laid down that approvals which affected drawings or specifications recently issued to manufacturers should not be replaced or amended within six weeks of the date of issue.

The growing menace of enemy aircraft activities in the autumn and winter of 1917-18 made it imperative that steps should be taken to protect the sealed drawings stored at Woolwich. Arrangements were made to store duplicate copies of sealed drawings held by the department at Woolwich in a place of safety—outside the air-raid zone—and by January, 1918, 7,000 duplicates had been prepared and stored in safety and the remainder of the work was being completed as rapidly as possible.[4]

In spite of the increasing pressure of demands for the preparation of sealed drawings and specifications for land service stores, sealed drawings continued to be made for certain Admiralty requirements. For instance, it was not until March, 1918, that the Admiralty undertook the preparation and amendment of sealed drawings for naval cartridges at the rate of five drawings per week. The issues of trench warfare

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[1] C.M. 4/3105; see also below, pp. 89-91.

[2] (Printed) *Weekly Report*, No. 40, XIII (6.5.16); No. 46, XIII (17.6.16).

[3] (Printed) *Weekly Report*, No. 98, XII (30.6.17).

[4] *Ibid*, No. 128, II (2.2.18).

drawings were also on an entirely different footing from the procedure in all the other departments of the Ministry. The usual procedure whereby all drawings were obtained from the Inspection Department was waived in the case of trench warfare stores to meet an emergency situation, and the trench warfare authorities retained negatives of their drawings and printed sufficient copies, with their own machines, to meet all demands.[1] This practice was felt to be undesirable as it led to confusion, drawings getting into the hands of the contractors which were not in agreement with the sealed drawings held by the Inspection Department, and the procedure was ultimately brought into line with that of the other divisions.

III. Extensions of the Ministry's Responsibilities for Inspection.

During the progress of the war, the Ministry was continually widening its sphere of activities. Thus further claims were made upon the Inspection Department until, in addition to the work undertaken in the divisions as organised in April, 1916, responsibility was assumed for the inspection of steel, minor components, aircraft and aircraft materials, mechanical transport, tanks and chemical warfare stores.

(a) Transfer of Steel Inspection.

In November, 1917, a further extension of the work of the department was made by taking over the inspection of steel of all kinds for land service use. Hitherto this work had been undertaken for the Ministry of Munitions by the Admiralty inspectors at Sheffield and Newcastle; but under the new scheme a directorate was established to deal directly with the work, and Mr. N. P. P. Sandberg was appointed Director of Inspection of Steel (Land Service). Certain existing laboratories with their equipment and a portion of their staff were handed over by the Admiralty and a new chemical laboratory and test house in Sheffield were equipped by the Ministry of Munitions, where the whole of the analytical work and the mechanical testing of shell and gun steel could be carried out.[2]

(b) Aircraft Inspection and Test.[3]

In March, 1917, the Ministry of Munitions became responsible for the inspection, as well as the production, of aircraft. Until this date, naval and military machines had been inspected by officers of the Admiralty and the War Office, and the organisation taken over by the Ministry included a large staff of inspectors for both services. The Aeronautical Inspection Department, which had previously examined all machines for the Royal Flying Corps, had a particularly large and important staff, which had developed to cope with the extensive manufacture of land service machines by numerous new contractors.

The task which confronted the Ministry of Munitions in taking over this work was no easy one. The production of a complete aeroplane was a much more delicate and intricate operation in 1917 than

[1] C.I.M./Gen./7152.
[2] For a more detailed account see Vol. VII, Part II, Chap. VII.
[3] Hist.Rec./H./1960/2.

it had been at the beginning of the war, and the large number of firms undertaking the production of aircraft supplies, without previous experience, meant the maintenance of a large body of officials to exercise close supervision over the contractors' works, while at the same time, the technical nature of much of the work made it very difficult to procure inspectors possessing the necessary qualifications.

The first duty of the Ministry of Munitions, upon assuming responsibility for inspection, was to decide between the respective merits of the naval and military methods of inspection, and to determine whether inspection should be associated with production, as was the custom in the Admiralty, or whether an independent department should be maintained. Finally it was decided to adopt the army practice, and a Director of Inspection of Aircraft was appointed to take charge of the new department, which was, however, an essential part of the organisation for aircraft production, and had no relations with the existing Munitions Inspection Department. The only change made from the Aeronautical Inspection Department's methods of test was the relaxation of the individual inspection of each of the small components, in the case of firms whose output had been satisfactory for a considerable time, and the substitution of examination by selection. Wider discretionary power was also given to the inspectors at the large works.

Owing to the separation of the Inspection Department from the flying services, a further change had to be introduced into the testing of machines when they were ready to leave the contractor's works. Previously aeroplanes had been flown for test purposes by the firms' pilots or by pilots on the inspection staff, but for the future it was arranged that the machine after being assembled at the contractor's works, should be tested by the Aeronautical Inspection Department for rigging and then handed over to the services who were to be responsible for the test flights.

The Air Board assumed responsibility for the design of aircraft and their accessories, but the Inspection Department was involved in a great deal of supplementary work upon materials. The scope of this work expanded very considerably under the Ministry, with increasing difficulty in obtaining materials. During the first two years of the war, timber inspection was confined to visual inspection of stocks of naturally seasoned wood, but in April, 1917, the Inspection Department began to work upon scientific lines. Artificial seasoning, by means of drying kilns, was introduced, and as the kiln owners had little experience in this work, the inspection officials in practice controlled the working of the kilns, keeping careful charts to show the temperatures and humidities to which the wood had been subjected during treatment.

(c) MECHANICAL TRANSPORT INSPECTION.

One of the greatest additional duties undertaken by the Inspection Department was the taking over of the responsibility for the inspection of mechanical transport in September, 1916. This was done gradually, a Director of Inspection of Mechanical Transport (D.M.T.I.) was

appointed who was responsible to the Director-General of Inspection of Munitions, and the greater part of the inspection staff who had worked under the War Office continued to carry out the same duties under the Ministry of Munitions. These exceeded considerably the normal functions of the inspector of military stores. Officers of the Mechanical Transport Inspection Department acted as "hasteners" of output as well as examiners of quality. They took an active part in procuring material and facilitating labour supply. They advised upon the placing of orders, finding new sources of supply. It was largely to their action that the successful production of vehicles in large numbers, as well as of good quality, was attributed.[1]

(*d*) THE INSPECTION OF TANKS.

The inspection of tanks gave rise to special difficulties and problems which were due in part to the exceptional circumstances in their evolution and to the urgent necessity of securing a large output at all costs. As much of the earlier work on tanks was of an experimental character, in which secrecy was of great importance, the inspection was mainly in the hands of the supply officers acting through inspectors who were responsible for progress as well as supply. In the case of the components such as steel castings, links, armour plate and engines, which were manufactured by a number of firms, the inspection was carried out by a small body of resident inspectors.

When tanks had passed the experimental stage and become an established item of supply, need for reorganisation of the method of inspection became imperative. Upon the establishment of a War Office Tank Committee in May, 1917, the Minister of Munitions (Dr. Addison) put forward the plea that there was no reason why the inspection of tanks should differ from that of other munitions, but that it should comply with the general principle that inspection was independent of supply. The fear that drastic changes in the inspection personnel might interfere with output prevented the Tank Committee from putting this recommendation into effect, but as serious complaints of the faulty inspection of tanks were general, the committee sought to carry out an improvement by proposing that a high official with great experience in the Inspection Branch of the Ministry should be appointed to assist and advise the Mechanical Warfare Supply Department, and that officers of the Tanks Corps should in future control the running trials of tanks at the various trial grounds before shipment.[2]

In spite of these measures, the inspection of tanks remained unsatisfactory, and it was reported that after tanks arrived in France, two or three weeks elapsed before they were ready to take their place in the fighting line, owing to the rectifications which were found necessary in consequence of faulty inspection at home. When production was being pushed forward at the highest possible pressure, it became clear that the inspection staff were inadequate to take the dual responsibility for progress and inspection. Experience proved beyond dispute that both

[1] See Vol. XII, Part IV, pp. 10–11.

[2] Vol. XII, Part III, p. 51.

output and inspection were suffering from the concentration of these two duties in the hands of a comparatively small number of inspectors or progress officers.

In August, 1918, steps were taken to reorganise the Mechanical Warfare Department and to place the Inspection Branch upon a more satisfactory basis. Responsibility was concentrated in a single committee known as the Tank Board, which controlled the inspection of tanks, as well as acting in an advisory capacity on all questions relating to them.

(*e*) THE SYSTEMATIC INSPECTION OF CHEMICAL SHELL.

The inspection of chemical shell, which increased enormously during the years 1916-1918, was hampered by the same difficulties that were experienced with tanks, owing to the fact that much of the work was experimental in character. The duty of the Inspection Department was to inspect munitions to approved drawings or specifications, but difficulties frequently arose in the case of chemical shell, where the object manufactured had been purely experimental in character, and the Inspection Department were called upon to carry out work which involved technical knowledge that they did not possess.[1]

In the early days it was impossible to lay down definite specifications under which inspection might be carried out, but as the nature and properties of the components of chemical shell became known, it was possible to draw up specifications, and in July, 1917, arrangements were made with the Inspection Department that the Director of Inspection (Chemical) should undertake inspection, and for this purpose central laboratories were established to which samples were sent for analysis.[2] The Director of Inspection (Chemical) was responsible for the correct composition of the chemicals used, and for revising the specifications. He also visited the factories to watch the process of manufacture, but he had no powers over the passing of filled projectiles, only coming into this matter at the request of the Director of Inspection of Gun Ammunition (Supervisory) for analysing the contents of selected shell as required.

The confidential nature of the operations required special conditions concerning access for visiting officers, and many of the most secret details were only communicated to the head inspector. In many cases also, it was found impossible in practice to get any clearly defined specification to agree with any drawing, and much hindrance to work and output was caused by the issue of specifications by the Inspection Department which proved in practice to be unworkable, or by the rejection of methods which had proved sound in practice.[3] An instance of the latter was seen in the case of 4-in. Stokes bombs, which had been jointed on with smooth cement by Messrs. Allbright & Wilson for some time; but when the Inspection Department took over the inspection, the bombs were rejected because they had not been jointed with red lead, although in the opinion of many well-qualified judges they were fit in every way for service.

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[1] HIST. REC./H/1650/10, p. 111. [2] *Ibid.*, p. 144. [3] *Ibid.*, p. 241.

IV. Development of Inspection in North America.

(a) Canada.

The need for closer relations between the inspection officials in Canada and the authorities at home was felt with increasing force during the summer of 1916. For some time Canadian inspection had not been able to deal adequately with the increasing munition output, and in view of the large programmes ahead, the Minister of Munitions felt that the whole system in Canada must be reorganised. The arrival of a large consignment of 6-in. shell which had passed the Canadian authorities and yet were glaringly defective, even to the naked eye, brought matters to a crisis. Colonel W. E. Edwards was sent to Canada to report on the situation, and in November, 1916, in view of his report, the Inspection Department in Canada was made directly responsible to the Inspection Department at home. Colonel Edwards was appointed Director of Munitions (Canada) with a seat on the Imperial Munitions Board, and Lieut.-Colonel Ogilvie continued to act as Chief Inspector, with the rank in the department of a deputy-director. A new section, under Captain A. C. G. Egerton, was created at the Ministry's headquarters, to act as a channel of communication between the Inspection Department in Great Britain and the Director of Inspection in Canada, and all communications between the various supply branches of the Ministry and Canada relating to inspection passed through this section.[1] Under the new scheme, the standard of inspection in Canada showed great improvement, and with the help of British inspectors and examiners, who were sent to Canada to help in the training of inspection officers and also to bring Canadian manufacturers more closely in touch with British standards, inspection difficulties were successfully overcome.

(b) The United States.

The military inspection department in the United States was reorganised in March, 1916. The headquarters were transferred to New York, so that closer touch might be maintained between the authorities respectively responsible for quantity and quality.[2] The staff was considerably strengthened under General Minchin, as Inspector-General, reporting through Mr. E. Moir, the Minister's representative in America, upon administrative questions, and to the Director-General of Munitions Design on technical points and questions relating to standards.[3] Owing to the uncertain mails and increasing transport difficulties, the home authorities had, however, much less complete information on many points of organisation and methods of inspection than was desirable. To remedy this state of affairs, the Ministry decided in October, 1916, to send Mr. A. H. Collinson (the Director of Inspection of Munition Areas) to New York, to make a special study of the methods of inspection adopted in the United States and the organisation of the department. Mr. Collinson was

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[1] (Printed) *Weekly Report*, No. 70, XIII (2.12.16).
[2] See Vol. II, Part III, p 46.
[3] C.R. 4452.

accompanied by Mr. G. R. Clarke, who devoted his attention to establishing a system of statistical information on the lines of the section at home, and Major L. St. J. R. Clutterbuck, who investigated the various difficulties of a technical nature which had arisen in regard to the quality of shell from America. Colonel L. R. Kenyon was appointed Director of Inspection in the United States. At the same time the inspection staff in the States was strengthened and the system of travelling inspectors was introduced with very beneficial results.

The inspection of steel, which had given great trouble owing to its unsatisfactory quality upon arrival in this country, showed marked improvement, which was partly due to the effects of the travelling inspectors who induced the manufacturers to take more care with the tests and partly to check tests and analyses being made by the department.

V. Growth of Testing Stations.

The task of the Inspection Department in the later stages of the war was one of great difficulty, as not only was the production of all classes of munitions increasing rapidly, but the shortage of trained or even partially trained officials was becoming still more acute. Only by improved organisation and concentration of effort could the situation be met, and the introduction of the system of central bonds and the construction of additional proof ranges did much to solve the problem.

(a) Establishment of Central Bonds.

Central bonds had the twofold advantage of combining efficiency with economy and were the development of a system which had been introduced early in 1915 in connection with the Ordnance Aircraft Factory Stores at Farnborough. In 1916 the Ministry of Munitions adopted the same procedure, by which a central bond was selected to which all the munitions manufactured within a certain radius were sent for inspection.

The value of this scheme can be best appreciated by a brief survey of its working in any specified locality—say, for instance, in the Manchester area.[1] There the local Munitions Committee had placed contracts for empty gun ammunition with some two to three thousand different firms, many of whom were only capable of producing a small output. Under the then existing arrangements for inspection, the inspectors had to visit the individual works, for in many cases the output was not sufficient to justify the appointment of a resident examiner or to employ fully the set of inspection gauges, at a time when there was a very great shortage in the supply of gauges. It was almost impossible for inspecting officers to supervise and control properly the work of their examiners in the very numerous widely scattered bond rooms, and it was not until arrangements were made with the Munitions Committee to transfer practically all the stores manufactured in the district to four central bonds for inspection that greater efficiency

[1] (Printed) *Weekly Report*, No. 48, XIII (1.7.16).

could be attained. Proper supervision at length became possible and the new system also helped to solve the problem of dilution of labour by giving greater scope for the employment of women. Gauges, moreover, could be gradually withdrawn from individual firms and concentrated for use, so that they were employed up to their maximum capacity and their accuracy could be regulated by constant checking with an ease which was under former conditions impossible. In addition to the Manchester district, inspection with central bonds was carried out by the Director of Inspection of Munitions Areas at Glasgow, Paisley, Edinburgh, Newcastle, Middlesbrough, Preston, Leeds, Sheffield, Liverpool, Derby, Birmingham, Bristol, Ipswich, Witham, Plymouth, St. Helens, Dublin and Belfast.[1]

(*b*) Increase in Proof Ranges.

In addition to the system of central inspection bonds, the policy of increasing the proof ranges for the testing of munitions upon a large scale, which was adopted in 1916, materially lightened the task of inspection. In April, 1916, it was decided to provide a proof range specially for trench warfare requirements, and a site at Buxton was selected. In August, 1916, the range was ready for use, and the proof of all trench howitzers and trench howitzer bombs was gradually transferred to Buxton where the inspection of howitzers and mountings was also carried out. In order that all the equipment might be kept together clinometers and periscopes were also inspected at Buxton. The scheme worked so well that during the first year extensions were made to both the buildings and the range area, and in May, 1917, owing to the congestion in the Inspection Department, more storage had to be erected, while changes in design which increased the range of the guns from 1,500 to 3,000 yds., necessitated an extension of the range area to 4,000 yds. by taking in additional land.[2]

Arrangements were made to establish gun proof ranges at Leeds, Birmingham and Nottingham. The first of these was begun early in 1917, when it was decided to construct a range to deal with the proof of all guns constructed and repaired in the Leeds area. A site was obtained at Meanwood, four miles from the Armley works, where the inspection both before and after proof was carried out. The first proof of guns on the new range was carried out on 3 January, 1918, and the experiment proved of value, in greatly reducing the time between the first delivery of the guns to Leeds and their final issue, and obviating the necessity of sending them to Eskmeals and back.

In July, 1917, a site at Bilberry Hill, near Birmingham, was selected for carrying out the proof of 4·5-in. howitzers and 18-pdr. carriages, and the construction of a proof range was pushed forward with all possible speed, and at the same time steps were taken to construct a range for the proof of guns in the Nottingham area.[3]

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[1] (Printed) *Weekly Report*, No. 48, XIII (1.7.16).
[2] Hist. Rec./H/1600/5; *cf.* (Printed) *Weekly Report*, No. 39, XIII (29.4.16); No. 98, XIII (30.6.17).
[3] (Printed) *Weekly Report*, No. 102, XIII (28.7.17).

The great development in the use of chemical shell made it essential to provide a large range where chemical shell could be tested with secrecy, and this was constructed at Porton[1] in 1916. A new range at Eltham was also equipped for carrying out experiments and tests with all varieties of fireworks used in warfare, in place of the existing firework range on Plumstead Marshes, which had become unsafe through the development of other danger buildings there.

VI. Growth of Staff.

(a) DIFFICULTIES OF EXPANSION.

One of the most pressing problems which still faced the Inspection Department upon its reorganisation in March, 1916, was the question of securing a supply of adequately trained officials to undertake the growing work of inspection. Much of the work was mechanical and could be satisfactorily performed by intelligent mechanics after a short course of specialised training, but in the higher grades where technical knowledge was required, very great difficulties were experienced. Ever since the outbreak of war, the shortage of more experienced examiners had been felt, and on 22 April, 1916, the Inspection Department again reported[2] that there was a great shortage of suitable men for first and second class examiners, which was partly due to the fact that the rate of wages, when the absence of piece-work was taken into consideration, did not compare favourably with those of experienced fitters throughout the country. Attempts were made to meet the situation by the extension of the use of female labour; by the re-adjustment of inequalities in wages and by the granting of a war bonus in July, 1916. Although for a time these measures relieved the situation, the department was constantly complaining that its employees, after a short period of training, would leave to undertake similar work in the Ordnance Factories, where the rates of pay were appreciably higher. In October, 1918, trouble arose with the skilled examiners because of the disparity between their rates and those earned by employees in Ordnance Factories and with private firms on time work, whose work the claimants were testing.[3] The matter was referred to the Chief Labour Adviser, with the result that an alteration in the existing scales of pay was approved and a temporary advance of 5s. to first and second class examiners was made.

The need for training a large staff of officials to deal with the great task of inspection was clearly recognised, and in May, 1916, a division of the Inspection Department was organised to deal with the provision and training of assistant inspectors and subordinate staff. Intelligent mechanics were found to train most satisfactorily as higher grade examiners, while in the lower grades, employees with many years' experience and good character were found to be very suitable for promotion as third and fourth class examiners.

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[1] Vol. XI, Part II.
[2] (Printed) *Weekly Report*, No. 38, XII (A) (22.4.16).
[3] (Printed) *Weekly Report* No. 162, II (5.10.18).

(b) THE INTRODUCTION OF FEMALE LABOUR.[1]

The introduction of female labour into the various branches of inspection proved a conspicuous success. Women had been introduced as viewers in the Ordnance Aircraft Factory Stores at Farnborough early in 1915,[2] but it was not until the spring of 1916, that they were employed for munitions inspection generally. They were then introduced as examiners in the optical instruments department, in filling factories, and Royal Laboratory danger buildings, and for fuses and shells of the smaller natures. They were also engaged and trained to measure the bore of guns, the exterior of guns and to examine gutta percha impressions and breech mechanisms. It was found in practice that it took about three weeks to train an intelligent woman to be a reliable and accurate gun measurer. In May, 1916, Messrs. Firth's National Projectile Factory at Sheffield introduced an innovation by employing women examiners for 60-pdr. shell, and the results were so satisfactory that they decided to extend their duties to the heavier natures. At the same time, in Glasgow, Messrs. Weir placed women on the inspection of 6-in. H.E. shell.

Women were also employed in the repair shops at Southampton, where damaged guns and carriages from overseas were overhauled and minor repairs carried out, and in September, 1917, for the first time, women examiners were used at Shoeburyness for firing tests, where they examined small natures of shell, both before and after firing, and dealt with proof fuses of certain natures.

In course of time, the extension of inspection duties allotted to women was not merely widened, but in those sections where women had been employed comparatively early in the war they were employed in ever-increasing proportions, and, wherever possible, used to set free male employees of military age. In certain sections, this dilution was quite 50 per cent. of the inspection staff, and even in August, 1916—a date at which the recognition of women examiners had not long left the tentative stage—the number of women examiners in the employment of the Inspection Department was computed to be approximately 15,000.

The same difficulties with regard to inequalities in rates of pay which were a source of trouble with the male staff made themselves felt in the case of women. In April, 1916, the Inspection Department feared that there would be difficulty in getting women examiners for Woolwich, owing to the higher rate of wages given in the Ordnance Factories, and discontent became general amongst women examiners in the summer of 1916, regarding the rates of pay. Petitions were presented by various groups of employees, and the Federation of Women Workers put forward a demand for an increase of 2d. per hour in the wages of all women workers, but as a whole, there was no general agreement amongst the women examiners in the extent of their demands. The matter was settled by a promised increase, and this with the war

[1] HIST.REC./H./900/3b; (Printed) *Weekly Report*, No. 41, XIII (13.5.16); No. 56, XII (26.8.16); No. 38, XII (22.4.16); No. 66, XII (4.11.16); No. 162, II (5.10.18).

[2] HIST.REC./H/1960/2, Chap. XXII, p. 4.

bonuses of July, 1916, and January, 1917, materially improved the position of the women employees. Amongst the older and more experienced women—the examiners, overlookers and assistant forewomen—a grievance still remained which was not removed until October, 1918. Experience proved that the system of fixed rates in these grades was not satisfactory, as the opportunity of promotion from one grade to another was very limited and the department found that they lost the services of the more experienced women, because after perhaps as much as three years' service, they were receiving the same rates of pay as those who had just passed the probationary period. This hardship was removed by the introduction of a system of annual increments, dependent on satisfactory service, within certain fixed limits within each grade.

(*c*) INCREASES IN PERSONNEL.

"The expansion of this department" said Mr. Winston Churchill, Minister of Munitions, in January, 1918,[1] "is one of the most remarkable features in the transition of British industries from peace to war. From a personnel of little more than 1,000 we have now expanded to nearer 70,000, and I am informed that the number of papers dealt with in a week by the Inspection Department aggregates over 600,000. This enormous expansion has been achieved only by dilution in its most daring and drastic application. The Military and Professional Officers who were here at the beginning were only a small handful, but it is due to their skill and character and industry that this enormous expansion has been possible without any deterioration, indeed with an actual improvement in the efficiency of the results.

Few things are more remarkable than the excellent quality of the munitions which we are making for our Armies in the field. The care which has been exercised at every stage has given our gunners and generals in the field a sense of absolute confidence in regard to the material they handle; and when we consider that enormous number of men and women of every trade and profession, class and calling in the country, who never saw a shell or a fuse before and were completely unprepared for work of this character, that have been brought in and are conducting this intricate and delicate and extremely responsible business from day to day, we are, I think, in the presence of facts on which as Englishmen we are entitled justly to congratulate ourselves."

VII. Summary.

Even a glance at the chart[2] showing the Ministry's organisation for inspection at the end of the war will suffice to realise the extent to which this work had expanded. The personnel of 1,300 all told at the outbreak of war had grown into a staff of 9,000 at the time of the Ministry's formation in the summer of 1915, and by the spring of 1916 numbered

[1] Conference of Inspection Departments, 15 January, 1918 (Mr. Collinson's Papers, No. 2).

[2] Appendix III.

19,000.[1] Its later development was still more remarkable. The enormous increases in manufacturing capacity, which resulted during the year 1916 from the Ministry's efforts to augment supplies, involved a corresponding increase in the arrangements for inspection. The preceding chapter has described this expansion in outline. The chart illustrates the main methods used, particularly the distribution of duties among a larger number of branches, and the general decentralisation of work, which were the principles agreed in October, 1915.[2]

The additional inspection duties transferred to the Ministry in this later period were partly undertaken by new branches of the existing Inspection Department, as in the case of mechanical transport, partly by independent inspection authorities more closely allied with the supply departments for the stores with which they were concerned. The enormous organisation thus built up numbered nearly 64,000 at the close of the war.

[1] See above, p. 43. [2] See above, p. 38.

CHAPTER VII.

THE MAIN PROBLEMS IN REGARD TO QUALITY.

I. Standards.

It is generally recognised that the standards of safety and efficiency attained by the British Army were exceptionally high in comparison with those of other nations. Very great value was invariably given to the factor of safety. It was, for instance, reckoned that gun ammunition had only attained a satisfactory quality when the risk of prematures had been reduced to virtual immunity, being of the order 1 in 250,000 or ·0004 per cent.[1] The maintenance of so high a quality in the production of stores in the enormous quantities needed for a European war was no easy matter.

(*a*) Conflicting Interests of Quantity and Quality.

Complexity of design and rigidity of test militated against large output. The formation of the Ministry of Munitions in the summer of 1915 intensified the normal conflict between design and the standards of inspection on the one hand and supply on the other. Unnecessary rejections meant enormous waste of labour and materials at a time when both were at a premium. Workshops were choked up by rejected stores. Transport arrangements, already overburdened, were hampered by the need for returning them for rectification. While the rigid system of manufacture to drawings and specifications within very close limits was applied by numerous comparatively inexpert examiners, to whom discretionary powers could not be entrusted, there could be little of the latitude which was needed to ease the burden of manufacture or to bring into action whole masses of new productive capacity. Such rigidity was in part due to the shortage of experienced technical staff, to whom discretionary power might more readily be given. The supply authority, concerned with shell manufacture,[2] or the filling and assembling of shell,[3] insisted that better results would be obtained, both in regard to serviceability and output, if inspection were left to a staff of supervisory experts, rather than to numerous comparatively unskilled examiners, working along mechanical lines. However this might be in theory, it does not ever seem to have been practicable to obtain technical staff in the numbers required.[4] Another cause underlying rigidity of inspection was a forgetfulness of the original reasons for fixing certain standards, which survived long after their first cause had ceased to exist. Thus, for instance, many unnecessary minor components were only eliminated from gun ammunition as the result of prolonged investigation by the supply officers in 1916-1917.[5] Similarly, in the

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[1] Mr. Collinson's Papers, No. 8.
[2] A.C. 3.
[3] *Ibid.*
[4] See below, p. 90.
[5] See Vol. X, Part V, p. 35.

winter of 1914-1915, while every pound of T.N.T. was urgently required, a regular output of the explosive in granulated form was rejected for shell-filling for several months, on the ground that it was not covered by the original specification, drawn up for the degree of fineness needed for exploder bags.[1]

On the other hand, the interest of the producer usually lay in the direction of large output rather than of high quality, and the knowledge of this state of affairs naturally prejudiced the design and inspection authorities against any proposals for changes in limits or methods of manufacture. Moreover, the bulk of the new contractors introduced in 1915 were unfamiliar with manufacture to the stringent limits essential in munitions production. Their complaints were often levied against a justifiable and necessary procedure as well as against its occasional misapplication.

(*b*) Effects of Combining Supply with Design and Inspection.

When large output was vital and manufacturing capacity small, as in 1915, the interest of supply was powerful enough to secure many modifications in standards. The transference of responsibility for quality to the supply authority at the end of 1915 was a deliberate effort to facilitate the modifications which were essential to the enormous increases in production then required. It was accompanied by a centralisation of responsibility for standards of quality in the military department of the Ministry, as a means of guarding against any undue importance being given to output as opposed to effectiveness and safety. The change resulted immediately in a largely improved elasticity—decisions as to the type of high explosive ammunition, long awaited, were received within a few weeks. By several important compromises, production was facilitated without any serious relaxation in regard to quality. Modifications already introduced in regard to steel specifications were widened to admit of new sources of supply; but the relaxations made were strictly limited to the material for certain smaller natures of shell and were never accepted for naval shell.[2] A system of grading certain stores, such as explosives, was introduced during the year 1916. Payment was regulated according to the quality of the produce, and, with explosives, the system worked well, when supplemented by absolute control of the market for commercial grades and by strenuous efforts on the part of supply officers to increase manufacturing efficiency.[3] Defective but slightly serviceable shell and components were accepted at reduced prices during the last two years of the war; but the danger of accepting really defective shell was at the same time lessened by the introduction of the hydraulic test.[4] There was, however, a certain disadvantage in accepting inferior stores at a lower price, even from the point of view of output; for these could conceivably be made in such large numbers as to increase the ease with which manufacturers gained their profits.

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[1] *Ordnance Board Minutes*, 12,135.

[2] See Vol. VII, Part II.

[3] See Vol. X, Part IV, p. 70.

[4] Hist.Rec./H/1340/4. Chap. IX, p. 4.

Thus, for example, one contractor preferred making shell of light weight for powder-filling at a low price to attempting to keep to the specification for lyddite-filled shell.[1] In some national factories under agency management, such as the National Projectile Factories, bonuses upon deliveries which passed inspection also gave a financial stimulus to good quality, and in most classes of the national factories a healthy rivalry between factory and factory resulted in an output of exceptionally high standard.

The comparatively low quality of the gun ammunition produced during 1916 was, in appearance only, a justification of the previous unwillingness of military authorities to modify standards or to transfer to a Ministry concerned with supply the duty of maintaining quality. It is clear that the defects in that year's output were mainly due to temporary causes, chief of which was the general inexperience among the managements and operatives of the new factories, particularly the filling factories. The supreme control of the Ministry hastened rather than hindered a general tightening up of inspection which took place as a result of these failures, and was only practicable by reason of the existence of the newly-established manufacturing capacity. The general quality of gun ammunition as tested by proof results improved enormously during the following year, so that by the end of 1917 an unprecedented standard had been reached in regard to quality as well as to quantity.[2] This result was due to many causes; among the most important were the increasing facility for studying design under practical conditions in the national workshops as well as round the council table, and the active interest taken by the supply officers of the Ministry in promoting industrial efficiency.

II. The Independent Status of the Inspection Authority.

This active intervention of the Ministry in regard to workshops efficiency was one of the main points in which its methods of supply differed from those of the War Office. Until the formation of the Ministry, the only representatives of the Government at munition factories were the inspection officers, and these watched actual manufacture in the case of certain stores only, notably guns and carriages. The inspector's primary duty was to sentence completed munitions on behalf of the State; not to assist the contractor by technical advice, nor to hasten progress.

Indeed, the main principle followed was that the inspecting officer should have no responsibility for production, a practice which had arisen from the lessons of the Egyptian Campaign in 1888.[3] It was only partially applied under the Ministry of Munitions, for in regard to his duties arising from the practical administration of tests, the chief inspection officer was regarded as within the Munitions Supply Department; and it was only upon technical questions relating to quality that he reported to the central military department of the Ministry,

[1] Mr. Collinson's Papers, No. 8.
[2] M.C. 372.
[3] See above, p. 7.

which was chiefly concerned with design. In some special cases the duties of watching progress and testing quality were combined with varying degrees of success. Tank production is a case in point. The local progress officers of the Mechanical Warfare Department were responsible also for inspection and the running tests of new machines. This arrangement was intended to economise staff and to protect manufacturers from a multiplicity of visits and from contradictory instructions. On the other hand, numerous defects in the machines, discovered after shipment, were attributed to these inspection officers' desire to hasten output.[1] It has, however, been seen that the results of combining the functions of hastening output and sentencing deliveries were satisfactory in the case of mechanical transport.[2] And again, in certain cases where the method of production was novel and the officers of the Inspection Department alone had the necessary technical knowledge, they even undertook with success the actual operation of plant, as was the case in the drying kilns for aircraft timber.[3]

One of the measures taken for improving the quality of gun ammunition towards the end of 1916 was the transference of the inspection of minor components from the filling authority to a distinct inspection authority.[4] The Controller of Gun Ammunition Filling operated chiefly through national factories and was in this respect on a par with the Chief Superintendent of Ordnance Factories, who was himself responsible for the quality of nearly all of the material and components used in his workshops. It was natural, therefore, that the Controller of Gun Ammunition Filling should see in the maintenance of numerous inspectors and examiners within his factories mainly a large waste of labour and time. His contentions were, moreover, supported by the large proportion of the inspecting staff to his operatives, which in some factories was as one to six; whilst difficulty in obtaining efficient examiners occasionally laid the Inspection Branch open to the charge that the factory operatives had to instruct the newly appointed examiners in their duties, or accepted on their staff operatives dismissed from the factories.[5] Both the Gun Ammunition Filling Department and the Small Arms and Machine Guns Department resented the intervention of the inspecting staff in intermediate stages of manufacture, maintaining that questions of factory efficiency and discipline were the sole concern of the supply authority. It was even at one time suggested (by Mr. Alexander Duckham) that the inspection of stores should be entirely transferred to the several supply controllers since the very existence of a separate Inspection Department had serious drawbacks. These he enumerated as divided responsibility, delays due to accumulations at works for inspection, differences in conditions of work and wages between operatives and inspecting staff, reduplication of work, and the over-insistence of inspectors upon "meticulous refinements," which were of no practical importance.[6] The heads of certain supply departments considered that the ideal method of

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[1] See Vol. XII, Part III, p. 51.
[2] See above, p. 78.
[3] See above, p. 77.
[4] See above, p. 71.
[5] Hist.Rec./R/261/35, p. 9.
[6] Hist.Rec./H/900/18, p. 6.

inspection was by a supervisory staff of experts, who should be empowered to use their own discretion, and should be maintained by the supply departments themselves.[1]

The obvious dangers of vesting in the supply officers entire control over inspection were, however, too great to admit of such a course. The Minister maintained the need for an independent inspection authority in January, 1917.[2] Many of the difficulties that had arisen between supply and inspection officers, *e.g.*, by reason of inconsistencies or sudden changes in the standards of inspection, were overcome by means of the regular meetings organised between the officers concerned with supply, design and inspection.[3]

Any increase in the discretionary powers of inspecting officers was a matter of considerable difficulty. Even the expert was in no very good position in this respect. It was said, towards the end of 1916, that "directly an attempt is made to determine not what is good or bad, but what is too bad, we are on dangerous ground where even expert opinion cannot move with certainty."[4] The supply officer would certainly have been a biassed judge as to the degree of accuracy or "meticulous refinement" that was of "practical importance." It was generally agreed that the real need was for a court of appeal as between inspection and supply, just as it was between design and supply.[5]

After the close of the war, a scheme was projected by the War Office, which might have ensured the military interests as regarded inspection while removing the drawbacks incidental to the existence about the factories of a large staff of inspectors attached to a separate Inspection Department. In March, 1919, it was decided that the function of design should return to the War Office, while inspection should remain with the Ministry owing to its close connection with supply. At the same time, the War Office indicated that the Design Department would probably establish a small supervising staff to ensure by personal inquiry and visitation that the military standard of inspection was faithfully maintained.[6]

III. Relations between Design and Supply.

The authorities dealing with design and supply came into close contact at three distinct points, viz., where experimental manufacture was concerned, where changes were needed to facilitate production, and where the programme for introducing a new pattern was in question.

(*a*) EXPERIMENTAL MANUFACTURE.

While experimental manufacture was one of the main functions of the Ordnance Factories, this duty was overwhelmed during the first 16 months of war in the more imperative call for output, and was only resumed in the early months of 1916, when the reserve manufacturing forces of the whole country began to come into full play.

[1] A.C. 3.
[2] See above, p. 75.
[3] See below, p. 93.
[4] Col. Galloway (Mr. Collinson's Papers, No. 8).
[5] A.C. 3.
[6] HIST.REC./H/900/18, p. 7.

The principle of allocating experimental manufacture to the State factories was generally pursued under the Ministry, partly with a view to secrecy, partly in order to avoid the difficulties which inevitably attended any settlement of contract terms for small, special orders. This work was, accordingly, undertaken by the Ordnance Factories or the new national factories and, in some instances, the departments concerned erected and administered small establishments for making models or producing samples on a semi-manufacturing scale. Cases in point were the laboratory at Grays, Essex, controlled by the Explosives Supply Department, and the experimental workshop in the Grosvenor Road established by the Trench Warfare (Design) Department.[1]

The facilities of the Ordnance Factories for experimental manufacture were reorganised under the Superintendent of Design,[2] and it was subsequently somewhat exceptional for complaints to be raised as to delay in the manufacture of experimental material.[3]

On the other hand, the manufacture of experimental stores was occasionally carried out by a contractor with considerable success and entire secrecy, as, for instance, in the production of the first tank; while the comparative reliance of the War Department upon the Royal Aircraft Establishment for the manufacture of experimental aeroplanes for military use not only gave rise to considerable jealousies among contractors, but also, by discouraging private enterprise, tended to limit the reserve of commercial manufacturing capacity in time of emergency.[4]

(*b*) Changes to facilitate Production.

Service designs which existed at the outbreak of war had been developed with regard to the main issue of providing an efficient and trustworthy store. There had been no question of reliance upon the reserve engineering capacity of the country, so that in the choice of a pattern the ability of the Ordnance Factory or the armament firms to manufacture had been the sole criterion of the practicability of supply. Similarly, the possibility of war on such a scale as to limit the quantities of the materials essential to munition production had apparently played no part in the decisions as to design. Thus, for instance, the limitations which shortage of materials imposed almost from the first upon the methods of making service cordite and high explosives had been entirely unforeseen. Alternative methods of manufacture had not been considered or approved. Alternative patterns did not exist even for making comparatively simple stores such as trench mortar ammunition in the ordinary engineering shops,

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[1] See Appendix IV.

[2] See above, p. 56.

[3] One such instance, for example, occurred in the case of star shells for the 5-in. B.L. howitzers. These were requested in July, 1917, when the factory's capacity was fully occupied upon the filling of naval star shells. The first 5-in. star shells, filled in September, 1917, failed at proof, and experimental work was still in progress during the December following (M.C. 402).

[4] See Vol. XII, Part I.

Hence from the time when the manufacture of munitions on an unprecedented scale first began to entail the use of new classes of productive capacity, the design authorities were at once overwhelmed with applications for changes in the service patterns in order to adapt them for manufacture in the ordinary workshops of the country.

It was largely due to the delays experienced in getting decisions upon such points that the Ministry eventually became responsible for design as well as supply. Military interests were thereafter safeguarded by the partial concentration of responsibility for design and by the purely military character of the Design Department; but the inherent difficulty of fusing satisfactorily the military and civilian elements in the Ministry was thereby enhanced.[1] Upon pressing questions relating to the development of 18-pdr. H.E. ammunition, close personal touch was maintained between the Ordnance Committee and certain officers of the Design and Supply Departments, and the solution of the main problems relating to the gaine and fuse was expedited during the winter of 1915-16. Even so, the practical difficulties of manufacturing the new type of graze fuse were not all appreciated, and it was not until an outside contractor received in April, 1916, detailed drawings for the filling of this fuse, that a defect in the design from the point of view of filling was disclosed. The peculiar difficulty of correlating the practical conditions of filling with the development o gun ammunition design accordingly led to a reconsideration of the general relations of the Design Department with the Supply Departments.[2] In June, 1916, the procedure in regard to design was revised.[3] *Liaison* officers from the supply departments were appointed to attend Ordnance Committee meetings at Woolwich as well as those in London, and the written concurrence of inspection and supply branches with proposed designs was to be obtained previous to approval. In particular, arrangements were made to utilise the experience which was rapidly being attained by the new filling factories as they started work during the spring and summer of 1916.[4] The minute which notified these changes in procedure enumerated the authorities which were available for consultation on the manufacturing aspect of design. They were the Superintendent of Design and the technical officers of the Ordnance Factories, the technical officers of the Inspection Department, the associate members of the Ordnance Committee, officials of the supply departments of the Ministry, representative manufacturers who were consulted from time to time, and the committee of manufacturers representing Boards of Management.

It was the responsibility of the Ordnance Committee to use these means of obtaining advice as to the practical aspects of design. The tendency seems to have been to rely almost invariably upon the old-established technical officers of the Ordnance Factories and the

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[1] *Cf.* HIST.REC./H/800/1, pp. 6–10, 20–21.
[2] C.R. 4470; *cf.* C.M. 4/1275.
[3] General Procedure Minutes, No. 13 (HIST.REC./R./263.8/11).
[4] See Vol. X, Part V, Chaps. I, IV.

Inspection Department, and to consult other authorities in a far less degree. Thus it was maintained by the Controller of Gun Ammunition Filling that proposals relating to changes in the designs for filling were invariably referred to the Ordnance Factories, but very rarely to himself, and this although the Ordnance Factories had remained outside the activities of the new National Filling Factories to which were due very remarkable developments in the methods of filling both shell and components.[1] Similarly, consultation with the committee of manufacturers, which had been established in December, 1915, as an advisory body on production generally, was almost immediately restricted to questions relating to gauges,[2] and almost invariably took the form of a reference to a single expert, Dr. Glazebrook, who acted as chairman of the committee and also as an associate member of the Ordnance Committee.[3]

Some more satisfactory method of correlation between design and supply became essential. It was secured in regard to artillery material as a result of representations made by manufacturers during the winter of 1916-17, that they could not work to the high standards required by service patterns.[4] In order to consider these questions, an Artillery Committee was appointed in March, 1917, for the correlation of design, inspection and supply. It consisted of heads of the departments concerned with these functions in regard to ordnance and shell manufacture.[5] In the case of other stores, the severance between the design and the supply authorities frequently had very grave results. There can be no doubt, for instance, that it hampered very seriously the production of chemical warfare stores.[6] It limited progress in the development and supply of munitions for trench warfare until October, 1917, when the position was remedied by housing the new Trench Warfare (Design) Department with the supply department, and by other arrangements for securing close co-operation between these two authorities. A concrete proof of the advantages attending this later method of decentralising design appeared immediately in the rapid development of the Livens projector.[7]

During the last two years of the war, the supply departments were mainly interested in the introduction of changes to economise material or money. The Metals and Materials Economy Committee appointed to consider this matter in November, 1916, included representatives both of design and supply.[8] Before any changes could be made, much research and experiment was needed to ensure safety and efficiency It was, however, found possible to make very considerable savings in scarce and valuable metals.[9]

Such changes were usually intended to facilitate production or to economise money and material. They went far towards this end; but experience occasionally proved that the changes were not satis-

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[1] Sec./Gen./2239.
[2] See Vol. VIII, Part III, p. 32.
[3] A.C. 65 (Shorthand Notes, 26.3.17).
[4] A.C. 65.
[5] Estab. Cent. 38/1.
[6] See Vol. XI, Part II, Chap. II.
[7] See Vol. XI, Part I, p. 11.
[8] General Office Notice, No. 71 (29.11.16).
[9] See above, p. 66.

factory, even from the producers' point of view. Thus, for example, changes to facilitate the block-filling of shell entailed the provision of a separate nose or base adapter instead of the "bottling" or closing in of the head. This alteration was at first welcomed by expert engineers; but it was subsequently considered that the provision of the shell in one piece had advantages which outweighed the elimination of the "bottling" process.[1]

(c) THE INTRODUCTION OF NEW PATTERNS.

On the whole the interests of supply were hostile to the introduction of new patterns. Any change in design dislocated the whole machinery for production and involved the alteration of plant and tools, the provision of new shop and inspection gauges, the re-training of labour and an enormous number of changes in all the minor operations of supply. Where bulk supply was obtained by means of repetition work, a clear run on large-scale production was essential to steady output. A check on the rate of production meant also a restriction of the contractor's profit and consequent rises in price. Frequent, and apparently needless, changes of pattern were upon occasion a source of very grave discontent, and it was impracticable to acquaint manufacturers with the causes, which sometimes led to an apparent *volte face*, in regard to design, such as, for instance, took place with the 3-in. Stokes mortar bomb during the summer of 1916.

The effects which a change in design could have upon output are well illustrated by the turn-over from the long gaine to the short gaine at the end of 1915. During the autumn, a weekly output of 100,000 rounds of H.E. shell of all natures had been promised, and from the beginning of October, 1915, this rate had been exceeded, the output of filled gaines being about 120,000 weekly. From about 29 October long gaines were only to be issued with a support and the provision of this support limited supply. About a month later the shortened gaine No. 2 with 10-grain detonators was approved. The conversion of plant to the manufacture of this gaine and the establishment of capacity for the detonators was at least a matter of six weeks; but on 2 December instructions were issued that no more long gaines would be accepted. In consequence, H.E. shell could only be issued in comparatively small numbers with fuses which needed no gaine. Issues of H.E. shell fell as low as 21,500 in one week during December. No issues of 18-pdr. H.E. were possible and the position only improved as the shortened gaine and fulminate detonator became available. Output of H.E. shell did not again reach the 100,000 a week until 22 January, 1916.[2]

The effects of changes in the design of gun ammunition were intensified, where the operations for filling and completing ammunition were concerned. The complexity of the designs for fuses and H.E. shell increased as the conditions of the war changed and the uses of H.E. shell developed. It was difficult enough to arrange for

[1] HIST.REC./R/1300/59.
[2] HIST.REC./H/1300/1 Enclosure G; *cf.* C.R. 4470.

providing numerous small components and for training inexperienced staffs and workers in performing a number of operations, each of which was trifling in itself, but of untold importance in its results. The difficulty was increased tenfold, when the nature of the store and the number and the kind of the operations changed frequently, as, for instance, occurred while the methods of detonation were being settled during the spring of 1916.[1] The arrangements for strengthening the *liaison* between design and supply authorities in June, 1916, were intended to minimise these difficulties.[2] They were accompanied by a revision of the procedure for introducing a new design. The design officer, in approving a new pattern, was to state the military urgency of its introduction. The supply department concerned was to be responsible for fixing the date and manner of the introduction. If a new design was considered satisfactory by the Design Department it was to be (*a*) approved provisionally for trial by troops and (*b*) approved finally. In the former case, the formalities in regard to specification, issue of drawings, etc., were modified in order to expedite the production of trial stores.[3]

These arrangements concerned standardised munitions in which the modification of pattern was of comparatively rare occurrence. Even with these, changes were frequently made to meet experience gained in the field or to facilitate manufacture under new conditions, but in the newer, and less standardised, classes of munitions the element of change was constant and no consecutive run of manufacture could be expected to any single pattern. Moreover, productive capacity had often to be organised before the final design was completely formulated and the pattern of the new store itself depended to an extraordinary degree upon conditions of supply. These facts were recognised in the peculiar administrative arrangements for designing, producing and inspecting such stores as aircraft, tanks, and the supplies for trench and chemical warfare.[4] One of the main difficulties experienced with regard to these was to settle that point at which the novel article became standardised, and thereupon to enforce the normal, comparatively rigid procedure upon authorities whose previous success had depended very largely upon a capacity for initiative and independent action.

(*d*) Time-lag in Design.

A considerable period of time is inevitably occupied in introducing a new store or modifying an existing store. Numerous stages have to be passed from the receipt of the Army's first request, usually couched in general terms, until the establishment of bulk output upon a regular basis. The first investigations must necessarily be followed by experimental manufacture and by tests for efficiency and safety. The success of experimental manufacture by no means implies a like success in bulk output, since the extreme individual care which is exercised in the production of trial stores cannot be applied to manufacture on a large scale. Administrative machinery for ensuring

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[1] C.M. 4/1275.
[2] See above, p. 93.
[3] Hist.Rec./R/263·8/11; *cf.* C.R. 4470.
[4] See above, pp. 48, 59, 63, 69, 77-79.

technical accuracy in manufacture, for keeping record of changes in pattern, and for providing the necessary drawings, jigs, gauges, etc., can be expedited, but not eliminated. The conversion of plant from one pattern to another may entail the building of entirely new machines, and the manufacture of new tools. The producer has to gain experience by actual manufacture before bulk output can begin. In any one of these stages, undue haste may lead in the end to much greater delay.

Let us take as an instance of modification the case of the graze fuse of which a chronology is given in Appendix V. Unsatisfactory results from fuse No. 100, with the long gaine, were reported in September, 1915, directly after the first issues of this fuse. The Ordnance Board immediately began investigations, which were continued, in a much more concentrated fashion and with extensive trials, by the Ordnance Committee, appointed in the following December. The ultimate form of this fuse (No. 101) with the shortened gaine of improved type (gaine No. 2 Mark II.) and the exploder container, which was an essential factor in the improved method of detonation, was approved for service in February, 1916. Temporary modifications were made to tide over the period of change in manufacture, but it was not till July, 1916, that output of fuse No. 101 began, and after that the supplementary supply of exploder containers was considerably delayed.

The development of the tank is a noteworthy instance of the time taken in introducing a novel store.[1] The general idea of a landship was under consideration for six months in 1915. There followed a period of six months devoted to the development of a particular pattern, which was formally accepted by the Army in February, 1916. A further six months was occupied in building up manufacture, so that bulk output began in August, 1916, special machines having been provided meantime for training purposes. In the case of the tank, a machine of great complexity, a single type was approved for service and made in comparatively small numbers for the first surprise attack of September, 1916. In consequence of this policy, and of the administrative difficulties described below,[2] there was a serious drop in output after the first use of the machines, and again before modified types could be introduced. A different method was frequently used in bringing out other new stores. Thus, several types of trench mortars, which were first demanded by the Army in October, 1914, were issued almost simultaneously. Improvised patterns were issued during the winter of 1914–1915, and designs which had been more closely studied during the following spring. This practice had the advantage of providing something at once; but the use of so many different types gave rise to serious difficulty in regard to training, besides adding to the problem of supply. With the spring of 1916, experience had, however, proved the superiority of certain types and had emphasised the desirability of eliminating types which could only be produced by restricting the output of other, more important, stores. It was accordingly decided to limit the number of patterns as far as possible.[3] This method of improvising to meet the immediate

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[1] See Vol. XII, Part III. [2] See below, p. 104.
[3] Vol. XI, Part I, Chap. III.

need and to tide over a period of detailed research had obvious advantages, and was often used not only in introducing absolutely new weapons such as the tank and the mortar, but also in adapting standard weapons to new uses, as was, for instance, the case in developing anti-aircraft guns.[1]

The choice of method was necessarily governed by military considerations, but an early decision was absolutely essential to successful production. For instance, delay in determining what chemical substances, if any, should be used in gun ammunition, resulted in a serious shortage during the summer campaign of 1916.[2] It was particularly necessary to have as long notice as possible for making chemical or explosive substances, for which a process of manufacture had first to be evolved and intricate plant constructed upon entirely novel lines. The erection of factories for a new class of store necessarily took longer than the establishment of plant to increase the amount of repetition work which could be done along well-known lines. It was, for instance, calculated in 1918, that it would take at least 18 months to build up the capacity for producing the new Farquhar-Hill automatic rifle in bulk.[3]

The amount of purely administrative work which was needed increased very considerably during the war. In each week there were approved some 3,000 changes in pattern of those standard munitions which fell within the province of the Director-General of Munitions Design.[4] The various stages in preparing and revising drawings and specifications occupied from three to thirty days. While the drawings were in course of preparation amendments were frequently received, and these became a fruitful cause of delay. It was accordingly arranged in June, 1917, that all approvals should be divided into two classes according to their relative urgency. The most urgent designs, where change was needed for the sake of safety, were to be amended as they were prepared. The drawings for the less urgent designs were to be amended only after six weeks, during which time all the necessary changes were allowed to accumulate.[5] Congestion in the drawing offices was thus somewhat relieved.

The concentration of all design duties in a single department was, doubtless, one cause of the difficulty which was experienced in hastening the machinery of design. As the activities of the Ministry grew, its sheer bulk increased the distance between officers in separate design and supply departments, and tended to disperse the technical knowledge of use and manufacture, upon the concentration of which speed in the improvement or development of pattern largely depended.

IV. The Bridge Between User and Producer.

After the establishment of the Ministry of Munitions the method of keeping in touch with the Army in the Field in regard to quality was

[1] See Vol. X, Part VI.
[2] D.M.R.S. 296.
[3] M.C. 680; D.D.G.(E.)/E.M.3/1009; D.D.G.(E.)/E.M.9/75.
[4] Minutes of the Artillery Committee, 30.4.17 (Mr. Collinson's Papers, No. 10).
[5] Minutes of the Artillery Committee, 26.5.17; 27.6.17.

subject to readjustment from time to time. It was necessary on the one hand to maintain the central authority of G.H.Q. and the Army Council; while, on the other hand, it was equally important that production should be guided by immediate and complete information as to conditions in the field and as to the behaviour of munitions already supplied.

(a) LACK OF CONTACT, JUNE-NOVEMBER, 1915.

So long as the general responsibility for design rested with the War Office, all communication as to the type and quality of munitions passed between G.H.Q. and that Department, and the Ministry was informed only on points which obviously affected supply questions, and that somewhat tardily. The Minister (Mr. Lloyd George) maintained that failure to communicate complaints which were received from the front as to the behaviour of particular munitions led to the loss of much valuable time in remedying defects.[1] This was among the most important of the considerations which led to the transference of responsibility for the quality of munitions to the Ministry.

Mr. Lloyd George was inclined to give a wide interpretation to that clause of the Order in Council, which in June, 1915, laid upon the Minister the duty of ensuring the supply, not only of the munitions which might be required by the Army Council, but also of those which might otherwise be found necessary.[2] In one or two exceptional instances he provided weapons of a type which he knew could be produced within a reasonable time rather than of the kind specially required by the Army Council, but impossible to supply in quantity and at once. A case in point is that of the medium trench mortar. The Department changed portions of a demand received in August, 1915, for 500 Vickers, and 500 2-in. mortars, placing contracts for 200 Vickers mortars only, and the rest for 2-in. weapons, which could be readily made by the ordinary engineer.[3] Still more striking was the authority given by the Minister on 12 August, 1915, to manufacture in bulk the Stokes mortar, which had been continuously rejected by the military authorities.[4]

(b) RELATIONS BETWEEN THE TECHNICAL DEPARTMENTS AND THE ARMY.

The transfer of the design authority to the Ministry in November, 1915, lessened the need for such drastic action as a means of ensuring adequate supplies. The Minister then requested that he should be kept acquainted with the behaviour of munitions in the field, both by the forwarding of frequent reports from G.H.Q. through the War Office and by means of visits to the front by representatives of the various departments of the Ministry for personal discussion and interchange of ideas. It was agreed that such visits should be made, but that no approval of design should be given, nor any demand for issue complied with, except on the authority of a formal communication sent from G.H.Q. through the recognised official channel.[5] The Design Department

[1] D.M.R.S. 252.
[2] See Vol. II, Part I, Chap. II.
[3] See Vol. XI, Part I, pp. 44–45.
[4] HIST.REC./H/1611/1.
[5] D.M.R.S. 252.

of the Ministry was eventually provided with an hour to hour *liaison* with the Western front by telephone and letter, and once a month an officer was sent to G.H.Q., France, with grenades or similar small stores.[1]

The main difficulty was accordingly experienced in departments dealing with novel stores, and in the Department of Munitions Inventions, which lacked any direct means of obtaining information as to conditions in the field, and was not in close enough touch with the Munitions Design Department to acquire indirect information with facility.[2] By an Army Order issued upon the formation of the Munitions Inventions Department, soldiers of all ranks who had inventive ideas were encouraged to visit the department's office. Such visits, supplemented by casual and unofficial visits from members of the department to the Western front, formed the chief means of obtaining information on points touching the stores for which the ultimate approval rested with the Munitions Design Department. On the vast mass of other military stores with which it was concerned, the Munitions Inventions Department obtained more direct knowledge of the conditions to be met, by means of intimate relations, which were established with the officials of the War Department, who were concerned with the stores.[3] Free communication from officers and men in the field was, however, checked by an Army Order issued in June, 1917, to the effect that all suggestions for new design should be submitted to G.H.Q., and that all ranks were forbidden to correspond with or visit departments of the Ministry in connection with questions of design or production, without written authority from G.H.Q.[4] The change was made at the instance of the Design Department and was partly intended to concentrate communications in that department. It was accompanied by a recommendation that all new patterns of stores should be sent to France through the War Office for trials, and that sample patterns should be accompanied by an estimate of the date of bulk production and information as to the effect of manufacture on the supply of other stores.[5]

While the Inventions Department was thus deprived of one of its main means of securing familiarity with the soldier's needs, the other departments of the Ministry which were dealing with novel stores were gradually acquiring a new intimacy with actual conditions in the field through the appointment of returned officers upon their staff. This was especially the case with the new Trench Warfare (Design) Department, which was formed in October, 1917,[6] and with the Chemical Warfare Committee[7] and the Tank Board[8] established in 1917. The personnel of the Ordnance Committee was similarly strengthened by the appointment of members with recent experience of active service and the new Controller of Munitions Design, Brigadier-General A. C. Currie, appointed in October, 1917, had himself recently returned from service overseas.[9]

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[1] D.G.M.D./Gen./011; D.G.M.D./Gen./36.
[2] A.C. 65.
[3] A.C. 65.
[4] 84/Gen./4575.
[5] *Ibid.*
[6] Vol. XI, Part I, p. 11.
[7] Vol. XI, Part II, Chap. II.
[8] Vol. XII, Part III.
[9] M.C. 514.

Similarly, the proportion of the military staff at the Royal Arsenal was increased as the war progressed until in the end four only of the twelve Superintendents or assistant superintendents of the factories were civilians. This policy was supported in 1918 by the Chief Superintendent, Sir Vincent Raven, on the ground that the first essential of a Government Arsenal was experimental and research work and that it was desirable that the assistant superintendent should be capable of giving an opinion as a soldier or a sailor during the preliminary stages of manufacture.[1]

Mr. Lloyd George's successors, Mr. Montagu and Dr. Addison, were mainly concerned with those questions of design which related to supply, *e.g.*, the use of substitute materials or changes in the method of manufacture.[2] In November, 1916, Mr. Montagu requested facilities for officers of the Inspection Department to investigate the behaviour of new types of guns and carriages in the field; but such requests had been restricted to a minimum.[3] Closer contact with the War Office was gained in January, 1917, by the presence of the Master-General of the Ordnance at the Fortnightly Meetings of Heads of Departments, and (later) by his membership of the Munitions Council.

During the latter part of the war, also, the increasing importance of the work of salvage and rectification led the Inspection Department of the Ministry to press for closer personal contact with the Ordnance Department in France, particularly in respect of the work of reconditioning ammunition.[4]

The Minister during this later period (Mr. Winston Churchill) had himself recently left active service in France when he took up this office in July, 1917. He held very definite opinions as to the type of equipment which it was necessary to provide at this time, and laid great stress upon the development of new methods of warfare by means of aircraft, tanks and gas, and upon increasing the means for rendering the Army mobile by evolving cross-country tractors and ropeways.[5]

Mr. Churchill's interest in tactical developments was evinced by personal conferences with officers in France, *e.g.*, with the officers of the Gas Services,[6] by the establishment in July, 1918, of a "Warfare" group of the Munitions Council to deal with inventions, novel stores and transport,[7] and by his appointment of a sub-committee in the Trench Warfare (Design) Department to "consider and advise upon possible improvements to the existing service stores used in trench warfare, and to devise new stores to meet requirements, or anticipated requirements, in the field." The committee consisted of representatives of the Trench Warfare (Design) Department and the Munitions Inventions

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[1] Evidence before the Engineering Sub-Committee of the Committee of Inquiry upon Woolwich, 1918.

[2] See above, pp. 65, 66.

[3] D.G.I.M./Genl./018.

[4] Conference, January, 1918 (Mr. Collinson's Papers, No. 2).

[5] Vol. II, Part I, Chap. IV.

[6] M.C. 1060.

[7] The group included Mechanical Warfare, Mechanical Transport, Trench Warfare (Design), Agricultural Machinery and the Munitions Inventions Department.

Department and during its short existence (from August to October, 1918), it was concerned chiefly with the development of body armour and of a convenient type of small arms ammunition box and with questions relating to barbed wire.[1]

The General Staff interpreted the activities of the sub-committee as definite attempts to short-circuit both G.H.Q. Overseas and the War Office at home, and considered that a similar tendency was shown by the proposed appointment of the Director of Gas Services, France, as President of the Ministers' Committee on Chemical Warfare and by a simultaneous suggestion from the Munitions Inventions Department for concentrating decisions as to the transport of guns in an individual officer under the Director General of Transport. Mr. Churchill agreed (17 October, 1918) that the General Staff alone exercised discretion as to what weapons or supplies should be placed in the hands of the troops. At the same time, he claimed for the Ministry the fullest freedom of suggestion and experiment. At a conference between the War Office and the Ministry on 21 October, 1918, it was agreed that the General Staff was responsible for the war organisation and efficiency of the Army, and the Ministry for providing what the General Staff required and also for developing and placing before the General Staff any suggestions as to improvements.

Finally a definite attempt was made to re-define the exact limits of the two Departments' functions. They were set out by the War Office as follows :—

The War Office was responsible for :—

(*a*) Deciding the nature and quantity of armament, and warlike material of every kind, indicating what additions and improvements in existing equipment were required ;

(*b*) Deciding upon the up-to-date efficiency or otherwise of all types of armament and equipment in existing use ;

(*c*) Approving the introduction into service of new designs of existing material, of additions to equipment or material which it was considered desirable to introduce and the introduction of new inventions for the purpose of increasing the efficiency of the Army.

The Ministry was responsible for :—

(*a*) Supplying such quantities of equipment and material allocated to the Ministry as the War Office might require, the design having been approved by the War Office in the first instance ; the Ministry being also responsible for inspecting all such stores before issue.

(*b*) Carrying on research, experiments and trials for the improvement in design of existing material and for new patterns of the same.

(*c*) Ensuring the trial and development of all inventions and of proposed alterations to existing equipments and for putting these before the War Office for decision as to their introduction into the service.[2]

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[1] Hist. Rec./H/1640/14, Chap. VI.

[2] 1/Gen. No./2236.

These limits were not definitely accepted or rejected by the Ministry, since the status of the supply authority passed under general revision at the close of hostilities. It should, however, be noted that the literal interpretation of the responsibilities of the War Office set out in section (*c*) would have restored to that Department the duty of sentencing patterns, which had passed to the Ministry in November, 1915, and was the chief function of the Controller of Munitions Design.

(*c*) LIAISON IN REGARD TO NOVEL STORES.

The need for exceedingly close touch between the designer, the producer and the user, was specially great where novel types of munitions were concerned. Here experiment was required not only to determine the method of production and the pattern of the store, but also to settle the most effective method of using it. In many cases the development of a new weapon involved very special arrangements for training the troops in its use, and peculiarly close relations were established between the designer, the supplier, and the training schools. Thus, the Clapham School for bombing instructors originated in the experimental ground set up by the section responsible for trench warfare research in May, 1915,[1] and extremely close relations were maintained between the authority responsible for producing the first tanks and the Motor Machine Gun Corps during the period of training in 1916.[2] Again, during the last six months of 1915, direct communication was maintained between the technical officers evolving apparatus for gas warfare at home and the officers of the gas services in the field.[3] Direct communication was also authorised between the supply authority and the Army in France in regard to the supply of certain improvised smoke ammunition which was urgently needed for the Battle of Loos;[4] but unofficial demonstrations of novel weapons at the front had obvious disadvantages, and met with protest on the part of military authorities.[5]

So far as trench warfare weapons were concerned, relations with the Army were maintained through the arrangements made for visits and *liaison* by the Design Department. Special procedure was necessary in the case of gas warfare. Here the nature of the article to be supplied depended very largely upon what was available and upon the practicability of applying various substances to military purposes. These were primarily matters for research at home, and until May, 1916, the research authority for the most part informed the gas services in France of what classes of substance could be supplied. A more definite settlement was made as to the nature of the chemical weapons and substances to be used, at a conference at the War Office in May, 1916.

Semi-official communications between the Trench Warfare Research Branch and officers of the gas services were frequent; but the main

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[1] HIST.REC./R/1600/20: *cf.* Vol. XI, Part I, p. 72.
[2] See Vol. XII, Part III, Chap. III.
[3] See Vol. XI, Part II, Chap. II.
[4] Vol. XI, Part I, p. 93.
[5] See, for example, Sir William Robertson on unofficial trials of the Stokes' Mortar in France, July, 1915 (HIST.REC./H/1611/1).

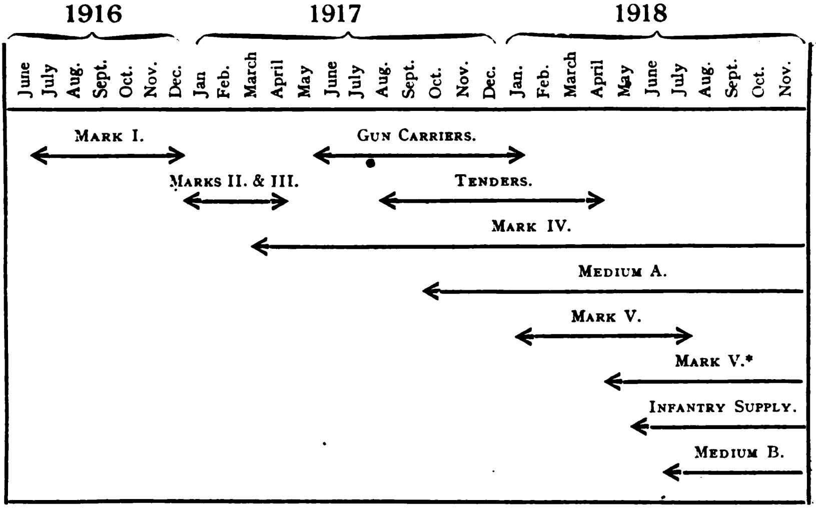
method of *liaison*, through occasional visits paid to the Western front by the superintendent of the experimental station at Porton, threw too much work upon a single individual to be perfectly successful. A further step towards the same end was made by the appointment of a representative from the War Office section dealing with gas warfare (A.9) upon the Chemical Advisory and Chemical Supply Committees. When the administrative organisation for chemical warfare was revised at the close of 1917, the Commandant, Overseas Artillery School, the Chemical Adviser, Home Forces, and representatives of the gas services in France became *ex-officio* members of the Chemical Warfare Committee ; but serious differences of opinion persisted between scientists at home and artillerists in the field as to the best methods of using different types of chemical shell.[1] In October, 1918, an attempt was made to overcome this difficulty by the appointment of the Director of Gas Services, France, as President of the Chemical Warfare Committee. It has already been seen that this measure threatened the central authority of G.H.Q., and of the War Office.[2] It was not long enough in existence to test its efficiency in correlating the experience of the Army in the Field with the deductions drawn by scientists from experiments at home.[3]

Experience in regard to the development of tanks illustrated the ill-effects upon output which can arise from lack of co-ordination between the user, the designer and the producer. After the introduction of the new war machine in September, 1916, the former close relations between the training camps and the supply officers broke down and the responsibility for further developments in the design was for some time a point at issue between the War Office and the Ministry. Meantime the authorities originally responsible for evolving and producing the first tank were ceasing to hold a unique position in their knowledge of its mechanism. The Tank Corps in the field was rapidly becoming acquainted with uses and defects which can only appear upon active service ; while the Tanks Directorate at the War Office was acquiring similar information from the experience of the training camps. Until October, 1917, these three authorities worked upon independent lines, and the *liaison* between them was sometimes non-existent and often unsatisfactory.[4] The results are clearly shown in the accompanying diagram which illustrates how output of the Mark I machine was entirely stopped in September, 1916, partly owing to indecision as to the number and type to be produced thenceforward, and was again broken, firstly, upon the change from Mark I to Marks II and III, in December, 1916, and secondly, upon the change to Mark IV, in March, 1917. In October, 1917, the appointment of an advisory Tank Committee representative of the Tank Corps overseas and at home, as well as of the supply authority and technical experts brought together all the interests involved. No absolute break in production occurred after this date, and later administrative difficulties concerned mainly the internal organisation of the supply department. By

[1] C.W.D. (A.) 48/34.
[2] See above, p. 102.
[3] See Vol. XI, Part II, Chap. II.
[4] Vol. XII, Part III, Chapters III and IV.

August, 1918, it was considered that there was no longer any need for the special military organisation which had till then been adopted for the development of a new arm. A somewhat exceptional means

PROGRESS IN THE CONTINUITY OF TANK DESIGN.



was, however, used for securing the consideration of all the interests involved. The formulation of manufacturing programmes and of general specifications together with the control of research and inspection thenceforward rested with the Tank Board, including the Master-General of the Ordnance, the G.O.C. Tank Corps, France, and the Controller of the Mechanical Warfare Department, and meeting under the presidency of the Deputy Minister, who was also Council Member for the "Warfare" Group.[1]

In the development of aircraft, the need for extremely close touch between the user and the producer was recognised from the first. Even while the Controller of Aeronautical Supplies had no authority in regard to design, he was, as a member of the Air Board, in continuous and close touch with the air services, and a special system of *liaison* existed between the Aeronautical Inspection Department and the Aircraft Acceptance Parks, in order to provide a link between the air services and the inspection and supply authorities.[2]

V. The Provision of Technical Staff.

Underlying practically all of the administrative difficulties described above was the problem of making the best use of a strictly limited number of highly expert officers. Throughout the war the work of technical departments was greatly handicapped by the dearth of military officers with the necessary technical knowledge.[3] The practice in time

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[1] Vol. XII, Part III, Chapters IV and V. [2] Vol. XII, Part I, Chap. III.
[3] HIST.REC./H/800/1, p. 14.

of peace of giving preference to army reservists in the less skilled grades of the inspection staff depleted these also just when the need for experienced men became most urgent.[1] The supply of experienced officers for the technical duties of inspection was exhausted early in 1915, and neither for that work nor for design duties were any officers available from the Ordnance College, which had been closed at the outbreak of war.[2] Every circumstance pointed to the future need of expanding the college in order to increase the number of officers trained in the technical aspects of the manufacture of artillery and weapons generally.[3] As a result of the shortage, all technical officers worked at very great pressure, while training had to be undertaken at a time of great emergency.[4] Some relief was obtained by the centralisation of technical duties; but this, in itself, hampered close co-operation between the technical and supply departments. In certain instances, moreover, the supply departments were driven to provide themselves with technical advisers, thus reduplicating expert staff.

The combination of supervisory and technical duties, in the case of inspection officers, added very considerably to the burdens borne by the comparatively small technical staff of the Inspection Department during the first eighteen months of the war. The method adopted by the Ministry for their relief in the spring of 1916 consisted generally in a separation of technical from supervisory duties, and the concentration of administrative control in a civilian organiser, whose responsibility in regard to technical questions was lessened by means of their reference to the head of the Design Department. There can be no doubt that the combination of these duties in peace-time was essential to advance in the science of munition production; during the war, the only alternative to their subdivision in the most difficult case, *viz.*, that of gun ammunition, was to sever responsibility for the numerous components of this store, a step which was considered highly undesirable in view of the close inter-relation of the components.[5]

VI. Conclusion.

Administrative methods for ensuring good quality play an important part in the successful provision of warlike stores. The relations between research, design, production and test are so intimate that ultimate effectiveness depends upon the facilities provided for a ready co-operation between the officers concerned with each of these tasks.

The experiences of a great war in this respect have been narrated above. When, in the summer of 1915, a ministry of supply was set up to produce the equipment for the growing armies, responsibility for design and the standards of inspection were retained by the War Department. By the end of the year, it had been found to be essential to success in fulfilling the enormous munitions programmes for 1916 and 1917, that these duties should be united with that of supply. Accordingly, the Ministry of Munitions became responsible for design

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[1] See above, p. 18.
[2] See above, p. 23.
[3] Hist.Rec./H/800/1, *loc. cit.*
[4] See above, p. 83.
[5] *Cf.* Hist.Rec./R./900/15.

and the standards of inspection in December, 1915. At the same time, the technical duties so transferred were concentrated in a strong military department within the Ministry, in order to safeguard the interests of safety and efficiency.

The immediate results of the transfer were to expedite decisions upon which depended the whole of the supplies for the summer campaign of 1916, and to render more elastic the system for securing changes needed to facilitate production and to make the most of the country's waning material resources. The Ministry's methods for securing these ends were modified in the light of experience. Regular conferences were established between officers of the supply, design and inspection departments, in order to prevent the undue separation of these authorities in a Department of such great bulk. Exceptional methods were applied to exceptional stores. The organisations eventually established for the design and inspection of novel stores, such as trench warfare or chemical warfare supplies, or of complex supplies, such as aircraft and tanks, provided for specially close contact between the supply officers and the corresponding technical departments.

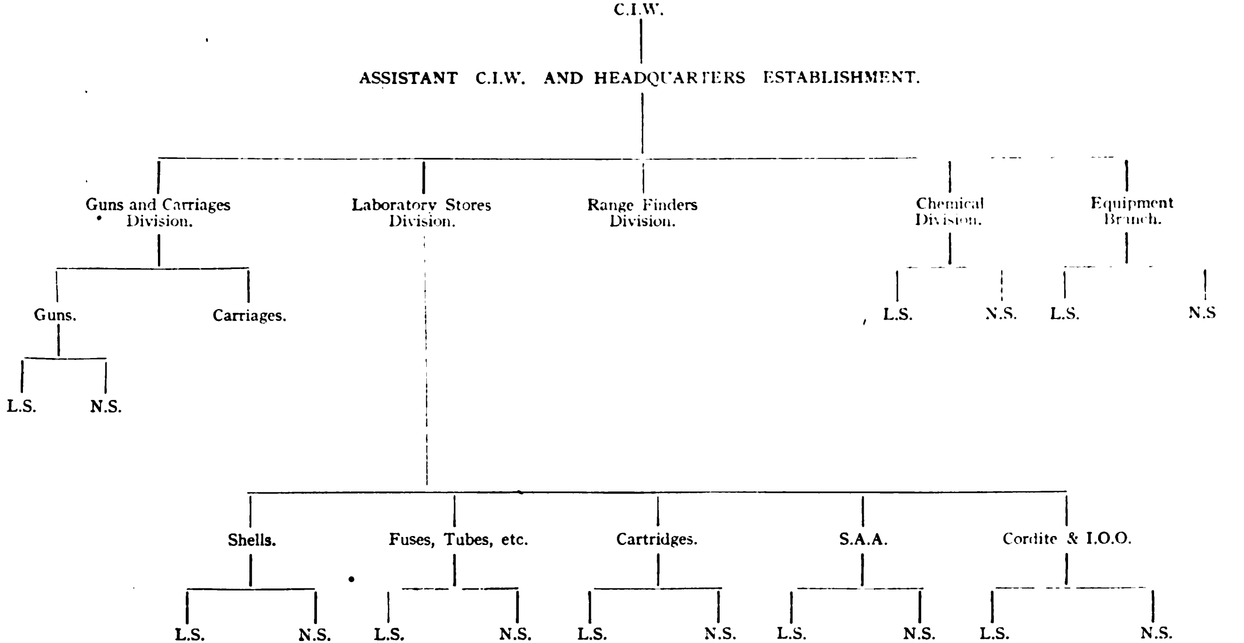
The maintenance of good quality in so large an output and under stringent economic conditions was a matter of considerable difficulty. The administrative problem of combining military and commercial knowledge in a single Department of State was not easy to solve. In spite of these difficulties, the technical achievements of the new Department were remarkable. New weapons were developed with success. Existing patterns were modified with rapidity to meet the changing exigiencies of the war. The general quality of the munitions supplied improved steadily, so that by the end of the war, British troops could place even greater confidence than before in the safety and efficiency of their equipment.

APPENDICES

APPENDIX I.

(Chapter II, p. 12.)

Organisation of the Inspection Department, Woolwich.—July, 1914.

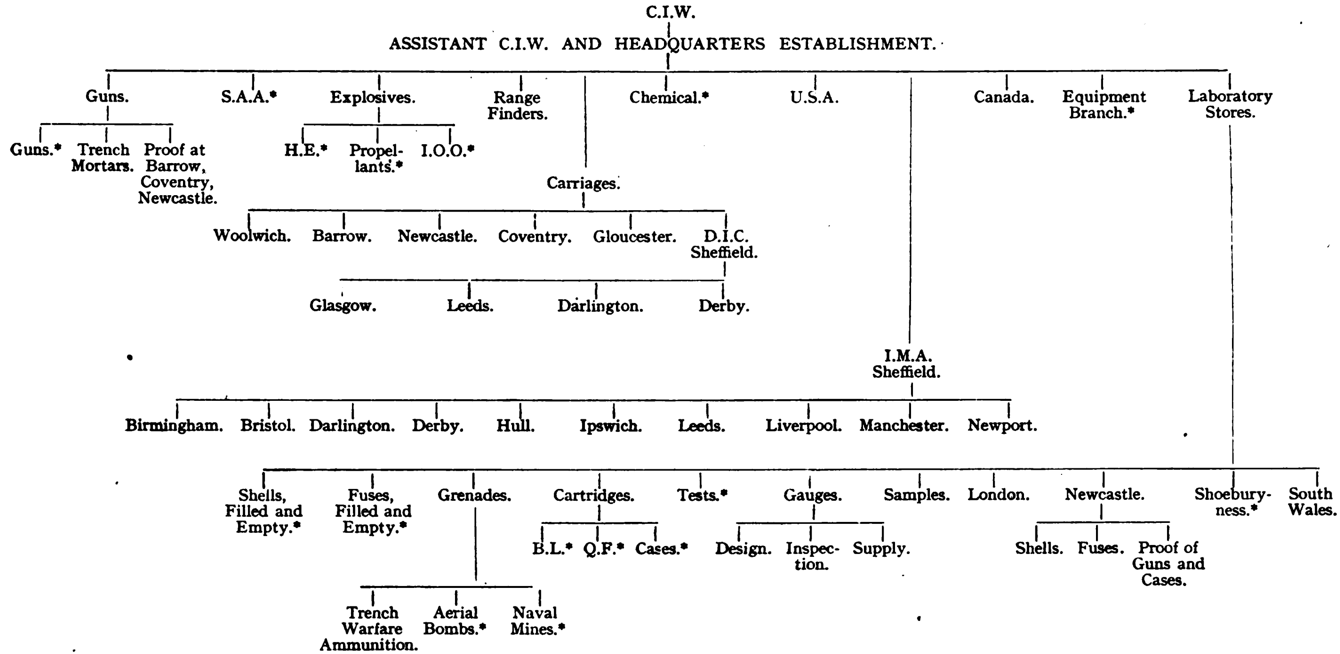


Approximate strength of personnel, 1,300.

APPENDIX II.

(CHAPTER III, p. 33.)

Organisation of the Inspection Department, Woolwich.—July, 1915.



* Divisions and sections marked thus dealt with Naval and Land Service supplies.

Approximate strength of personnel, 9,000.

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chanical Warfare		
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OTAL	..	63,800

APPENDIX IV.

(CHAPTER V, p. 60.)

List of Experimental and Research Establishments under Ministry Control.[1]

Name.	*Nature of Work.*
Research Department, Woolwich	Investigations as to ballistics, metallurgy, explosives and their application for all services.
Shoeburyness Experimental Establishment.	Experiments with ordnance, etc.
Hythe Experimental Establishment.	Experiments with small arms.
H.M. Laboratory, Chiswick ..	Chemical research on explosives.
Institute of Chemistry, Analytical Laboratory.	Research on coal tar products.
H.M. Laboratory, Grays (Grays Chemical Works, Ltd.).	Semi-manufacturing scale experiments on explosives.
Perivale N.F.F., Standard Production Unit.	Components production under ideal conditions.
Brentford Research Foundry ..	
Royal Aircraft Establishment, Farnborough.	Full-scale experiments on aeroplanes and research as to aircraft materials and accessories.
Aircraft Inspection Laboratory, Gower Street, London.	Miscellaneous research as to the design and construction of aircraft, particularly materials.
Grosvenor Road Experimental Workshop.	Experimental manufacture of trench warfare stores.
Clapham Common Experimental Ground.	Trials of trench warfare apparatus.
Richmond Park Experimental Ground.	Trials of ropeways.
Porton Experimental Ground, South.	Trench mortar range and experimental ground.
Porton Experimental Ground, North.	Chemical warfare research and large scale experiments.
Wembley Experimental Ground	Chemical warfare research and small scale experiments.
Dollis Hill Experimental Ground	Research and experiment on tanks.

[1] This list is based mainly on Estab. Cent. 1/281; it includes only those establishments whose main work related to research, and not those engaged primarily upon manufacture, such as the Ordnance Factories and the new national factories established under the Ministry, or upon other operations, such as the various proof ranges. It does not include the technical sections or committees which formed part of the Ministry staff.

APPENDIX IV—*contd.*

Name.	*Nature of Work.*
Oldbury Experimental Ground	Research and experiment on tanks.
University College Laboratory, London.	Anti-gas research.
M.I.D. Workshop	Manufacture of models.
Imber Court Experimental Ground.	Miscellaneous research for M.I.D. on artificial limbs, engineering equipment, internal combustion engines, and acoustics.
Claremont Park Experimental Ground, Esher.	Trials of bombs, grenades, rifles, armour, fuses and tests of engines under varying atmospheric pressure.
M.I.D. Sub-Station, Chattenden, Chatham.	Research and trials of boring in chalk and clay.
Whale Island Anti - Aircraft Section.	Development and tests of anti-aircraft apparatus and research in high-angle fire.
Stokes Bay Anti-Aircraft Experimental Station.	Research in use of sound-locating instruments.
Rochford Anti-Aircraft Experimental Sub-Station.	Research on design of sound-locating instruments.
Ramsay Laboratories, University College (part).	Research on fixation of atmospheric nitrogen.
Institute of Chemistry Laboratories (part).	Investigation into uses of waste chemical products.

APPENDIX V.

(CHAPTER VII, p. 97.)

Chronology of the Development of the Graze Fuse.

December, 1914 ..	Approval of gaine No. 1. Approval of fuse No. 100 with gaine No. 1.
January-April, 1915 ..	Minor modifications in the design of fuse No. 100.
February, 1915 ..	Drawings of fuse No. 100 completed and sealed.
June, 1915	Output began of (empty) fuse No. 100 with gaine. Meantime H.E. shell issued with fuse 80/44 and gaine.
June-November, 1915..	Trials with 10-grain detonator to improve detonation of gaine.
July, 1915	Filling of fuse No. 100 with gaine No. 1 began.
August, 1915	Issues of fuse No. 100 with gaine No. 1 began. Prematures in France ascribed to set-back of gaine.
September, 1915 ..	Unsatisfactory reports on fuse No. 100 from France.
October, 1915	Decision in favour of a shortened gaine (No. 2, Mk. I).
November, 1915 ..	Approval of 10-grain detonator below gaine. War Office refused to accept any more long gaines.
December, 1915 ..	Unsatisfactory reports from France on the shortened gaine.
January, 1916 ..	Output began of gaines with 10-grain detonators.
February, 1916 ..	Approval of gaine No. 2, Mk. II.; approval of fuse No. 101, and of temporary modifications of fuse No. 100, viz., Nos. 102, 103; exploder container to be issued as soon as possible.
April, 1916	Issue of drawings for fuse No. 101 to contractors; attention drawn by a contractor to impracticability of filling to the design for fuse No. 101. Bulk output of fuses Nos. 102 and 103 began.
May, 1916	Manufacturers changed to gaine No. 2, Mk. II. Inspection and issue of fuses Nos. 102 and 103 began.
May-September, 1916..	Manufacturing difficulties in regard to the exploder container.
July, 1916	Output of No. 101 began.

APPENDIX VI.

(CHAPTER V, p. 64.)

Table Showing Advances in the Efficiency of Aircraft.

Aeroplane.	Engine.	Date.	Speed at 10,000 ft.	Air Endurance.	Service Ceiling.	Time to climb 10,000 ft.	Load.
			m.p.h.	hrs.	ft.	min.	lbs. per h.p.
Fighting Scouts (Single Seater)—							
Bristol Scout	80 Gnome	1914	86·5	2½	15,500	21·3	14·2
Sopwith Scout	80 Le Rhone	1914	108 (at ground)	2¼	—	—	14·5
Martinsyde Scout ..	160 Beardmore	1915	99·5	4½	16,000	15·2	14·5
Sopwith Pup	80 Le Rhone	1916	104·5	3	17,500	14·4	14·6
Sopwith 1½ Strutter ..	130 Clerget	1916	97·5	4½	15,500	17·8	17·2
S.E. 5	150 H.S. ..	1917	132·5	2½	22,000	11	10·1
S.E. 5a	200 H.S. ..	1917	121 (at 15,000)	3	22,000	10·3	9·3
Sopwith Camel ..	B.R. 1 ..	1917	121	2½	22,000	8·2	9·8
Sopwith Snipe ..	B.R. 2	1918	124·5	2¼	19,500	8·8	8·75
Martinsyde F. 4[1] ..	300 H.S. ..	1918	143·5	1⅗	26,000	6·9	7·5
Two Seater Reconnaissance and Fighting Machines.							
B.E. 2a	70 Renault	1914	73	—	—	9 min. to climb 3000	—
B.E. 2c	90 R.A.F. ..	1914	72	3¼	10,000	20 min. to climb 6500	22
Vickers Fighter.. ..	100 Mono ..	1915	73 (at ground)	—	7,000	30 min. to climb 6500	18
R.E. 8	150 R.A.F...	1916	93	4¼	13,500	22	16·3
F.E. 2b	160 Beardmore	1916	76	3½	11,000	39·7	17·9
F.E. 2d	250 R.R. ..	1916	88	3½	12,000	32·5	14·5
Bristol Fighter	250 R.R. ..	1917	113	3	20,000	11·25	11·0
D.H. 4	375 R.R. ..	1917	133·5	3¾	22,000	16·5	9·3
D.H. 9	200 B.H.P.	1918	110	4½	16,500	18·7	13·8
D.H. 9a[2]	Eagle VIII.	1918	125·5	4¼	20,000	12·2	11·0

[1] This aeroplane did not see service.
[2] Without load of bombs.